



NASA Conference Publication 10179

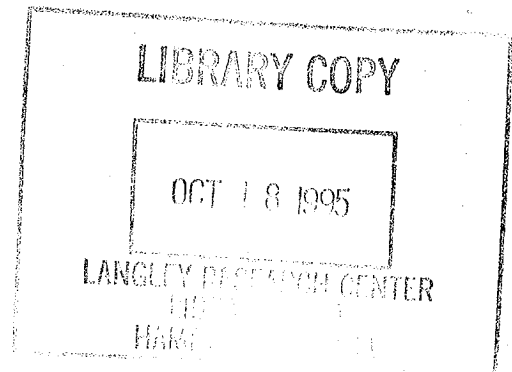
NASA-CP-10179 19960002340

# Prospects for Commercialization of SELV-Based In-Space Operations

---

*Compiled by  
Stephen J. Katzberg and James L. Garrison, Jr.  
Langley Research Center • Hampton, Virginia*

**FOR REFERENCE**  
**NOT TO BE TAKEN FROM THIS ROOM**



Proceedings of a workshop sponsored by the  
National Aeronautics and Space Administration,  
Washington, D.C., and held in  
Newport News, Virginia  
October 18-19, 1993

September 1995

Printed copies available from the following:

NASA Center for AeroSpace Information  
800 Elkridge Landing Road  
Linthicum Heights, MD 21090-2934  
(301) 621-0390

National Technical Information Service (NTIS)  
5285 Port Royal Road  
Springfield, VA 22161-2171  
(703) 487-4650

**PROCEEDINGS OF THE SELV-BASED  
IN-SPACE OPERATION WORKSHOP**

**OCTOBER 18 - 19, 1993**

**OMNI HOTEL**

**NEWPORT NEWS, VIRGINIA**







# **Prospects for Commercialization of SELV-Based In-Space Operations and Logistics**

Proceedings of a Workshop Held October 18 & 19, 1993

Langley Research Center organized a workshop to assess the role that small expendable launch vehicles (SELV's) can play in space operations. The goal of the workshop was to identify viable opportunities for commercial in-space support and logistics operations.

The workshop plan was to bring together owners, operators, and insurers of space-borne assets both government and private, along with commercial technology suppliers and government researchers. Another objective of the workshop was to help identify the role that NASA can play in joint research, including making facilities available, developing selected common interfaces, and encouraging industry standards.

It was also hoped that the workshop would provide an opportunity for the technology suppliers to interact with a significant body of their potential customers. The workshop interaction would also permit the potential customers to judge the level of interest in supplying commercial on-orbit services.

The workshop was divided into four sessions: First, the requirement for on-orbit services was developed by reviewing the NASA-sponsored Intec Study, the communication satellite manufacturers' viewpoint, and the satellite insurance company's assessment of opportunities and realities in this area. Second, the SELV manufacturers presented sketches of the capabilities that they expected to be able to provide to support in-space operations, including capabilities to geostationary orbit. Third, a look at several scenarios for in-space operations and potential flight experiments were given. Fourth, a synthesis and assessment was made to determine whether there were, in fact, real commercialization opportunities for SELV-based missions.

The salient points developed during the workshop were that for geostationary missions only a few opportunities exist, primarily due to the lack of already incorporated interface hardware in the geostationary satellites. Possible opportunities exist for rescuing geostationary-transfer-orbit stranded satellites. A major enabling factor in on-orbit operations is the existence of a reliable background business base on which to build the occasional rescue mission. Such a business could be a role for launch on demand and small payload logistics support to Space Station. Essential to the latter is the role the government can play in ensuring an opportunity for participation of SELV-based logistics during and after the Space Station development phase.

41 In addition, it was felt that in low-earth-orbit satellite systems, significant future technology paths exist that have in-space operations as a fundamental element. It was suggested that much could be gained by studying the experience gained in deep sea mining and oil well drilling. This activity showed that the mining and oil drilling industry accepted robotic techniques only through demonstration, in large part sponsored by government. Thus, demonstration missions provide at last one way to build the necessary confidence in on-orbit operations and the impetus for such experiments will most likely come from the government.

Stephen J. Katzberg  
February 1994

## **SELV-Based In-Space Operation Workshop**

### **October 18, 1993**

8:00 - 8:30	Registration	
8:30 - 8:45	Welcome	<b>Brian Pritchard</b> LaRC/STIO
8:45 - 9:00	Overview/Introduction to Workshop	<b>Steve Katzberg</b> LaRC/ASCD
9:00 - 9:30	Space Repair and Salvage, Insurance Industry Role	<b>Jeffrey S. Cassidy</b> U.S. Aviation Underwriters, Inc.
9:30 - 9:45	Communication satellite technology: servicing, resupply - is it practical?	<b>Mike Leonard</b> Space Systems/ Loral
9:45 - 10:00	NASA Communication satellites with comments on rescue or resupply	<b>Jim Maley</b> NASA Code OX
10:00 - 10:30	Summary of the INTEC Study	<b>George Levin</b> NASA Code DD
Informal Break		

# **SELV-Based In-Space Operation Workshop**

## **October 19, 1993**

9:00 - 9:30	Fairchild experience and systems related to in-space ops and service	<b>Bill Hohwiesner</b> Fairchild
9:30 - 10:00	Ranger	<b>Dave Akin</b> University of Maryland
10:00 - 10:30	Lessons gained from undersea operations that bear on space operations	<b>John O'Donnell</b> Oceaneering Space Systems
10:30 - 10:45	Break	
10:45 - 11:30	An initial mission set	<b>Davy Haynes</b> LaRC/STIO
11:30 - 12:00	Discussion	<b>All</b>
12:00 - 1:00	Lunch	
1:00 - 3:00	Synthesis Additional Missions Prioritizing the Missions by Financial Impact Assessment of the Technical Readiness of the Missions	<b>All</b>

10:30 - 11:00 Sensitivity analysis developed from INTEC study

**Peter Stark**  
Consultant

11:00 - 11:30 Background on the INTEC Study financial analysis and relationship to commercial potential

**Robert Schick**  
KPMG Peat Mar wick

11:30 - 12:00 Development of requirements for unmanned Space Station logistics

**William Cirillo**  
LaRC/ASCD

12:00 - 1:00 Lunch

1:00 - 1:30 Presentation of EER's SELV launch system family

**Jack Koletty**  
EER Inc.

1:30 - 2:00 Presentation of Lockheed LLVI and growth versions

**Larry Langston**  
Lockheed

2:00 - 2:30 The Martin Marietta MSLS launch system

**Pat Albert**  
Martin Marietta

2:30 - 3:00 Orbital Science on Pegasus & Taurus

**Chris Schade**  
OSC

3:00 - 3:30 The Space Automation & Robotics Center technology development program

**Mike Dobbs**  
ERIM/SPARC

Informal Break

3:30 - 4:00 Robotics systems past and present applicable to small expendables

**Ralph Will**

4:00 - 5:00    Space guidance controls, and navigation  
                  technology for small expendable technology

**Dan Moerder**  
**Ray Montgomery**  
**Kevin Dutton**

5:00 - 5:30    The CTA/ORBEX launch system

**Steve Thibault**  
CTA Launch Svcs.

PROSPECTS FOR COMMERCIALIZATION OF SELV-BASED IN-SPACE OPERATIONS WORKSHOP (PREFACE)	iii
AGENDA	v
TABLE OF CONTENTS	ix
SUMMARY OF SESSIONS	1
 SESSION I	 23
 SUMMARY	 25
SPACE REPAIR AND SALVAGE - INSURANCE INDUSTRY ROLE Jeffrey S. Cassidy, United States Aviation Underwriters, Inc.	33
SELV IN-SPACE OPERATIONS Mike Leonard, Space Systems Loral	54
OFFICE OF SPACE COMMUNICATIONS Jim Maley, NASA	59
NASA/INTEC 90-DAY SATELLITE SALVAGE STUDY George Levin, NASA	75
SPACE STATION LOGISTICS REQUIREMENTS William M. Cirillo, NASA Langley Research Center	105
 SESSION II	 123
 SUMMARY	 125
EER SYSTEMS SPACE PRODUCTS GROUP Jack Koletty, EER., Inc.	129
LOCKHEED LAUNCH VEHICLES Larry Langston, Lockheed Missiles and Space Company	165
MSLS MULTI-SERVICE LAUNCH SYSTEM Pat Albert, Martin Marietta	187

PEGASUS AND TAURUS 215  
Chris Schade, Orbital Sciences Corporation

AUTONOMOUS RENDEZVOUS AND DOCKING 243  
Micheal E. Dobbs, ERIM/SpARC

SPACECRAFT GUIDANCE CONTROLS AND NAVIGATION 289  
TECHNOLOGY FOR SMALL EXPENDABLE TECHNOLOGY --- CONTROLS  
Raymond C. Montgomery, NASA Langley Research Center

GLOBAL POSITIONING SYSTEM (GPS) SPACECRAFT CAPABILITIES 299  
AND APPLICATIONS  
Kevin Dutton, NASA Langley Research Center

INTRODUCTION TO CTA LAUNCH SERVICES 319  
Steve Thibault, CTA Launch Systems

SESSION III 349

SUMMARY 351

TECHNOLOGY - WHAT IS POSSIBLE 359  
Bill Hohwiesner, Fairchild Space

UNDERSEA SERVICING ANALOGS - LESSONS LEARNED FOR SPACE 407  
SERVICING  
Jim O'Donnell, Oceaneering Space Systems

MISSION ANALYSIS FOR SMALL ELV-BASED IN-SPACE OPERATIONS 423  
Davey Haynes, NASA Langley Research Center

SESSION IV 455

SYNTHESIS AND GOVERNMENT ROLE 457  
Dr. Stephen J. Katzberg, NASA Langley Research Center



**SUMMARY OF SESSIONS  
FOR THE  
SELV-BASED IN-SPACE OPERATION WORKSHOP**

**OCTOBER 18 - 19, 1993**

**OMNI HOTEL**

**NEWPORT NEWS, VIRGINIA**

# **Summary of the SELV-Based In-Space Operation Workshop**

## **October 18-19, 1993**

### **Hampton, VA**

#### **SESSION I**

Jeff Cassidy, U.S. Aviation Underwriters, Inc.

There was a wide fluctuation in insurance rates and capacity between the mid-1960's and the mid-1980's. Since that time, the insurance market has been stable with a current market capacity of \$300M- \$350M. Despite losses in the early 1990's, rates have remained relatively constant.

Property coverage is divided into three phases:

- Launch
- Initial on-orbit checkout
- On-orbit operations (through end of satellite life)

Rates and insurability are based on projected reliability from the spacecraft provider plus past experience.

In regards to insuring Space Repair, Logistics and Salvage Missions, Mr. Cassidy noted:

- Insurance has been available for SELV missions.

- Concerns are:
  - Technical complexity
  - Hardware performance history
  - Testing and Quality Control Approach
  - Company qualifications (including subcontractors)
  - Loss criteria under the policy
  - Perceived probability of success
- It is important to involve the insurers early in the design process for new systems.
- Insurance is only one element of risk management (e.g., reliability, redundancy, etc.).
- Each mission will be underwritten and priced separately.
- Terms and conditions will be tailored to the risks and requirements of the mission.

3 Specifically with respect to Salvage, Mr. Cassidy noted:

- After claims payment, insurers often have salvage rights.
  - (Westar 6 and Palpa B2 are the best examples)
- To obtain salvage, insurers may:
  - Allow insured to operate (in degraded mode); insurer receives part of revenues
  - Take title and sell
  - Repair and sell
- Repair or resupply capability may enhance the value of salvage.

- On-orbit salvage is appealing if:
  - Costs are low in comparison to gain
  - High probability of success
  - Technically sound approach with low risk to healthy satellite subsystems
  - Flight proven (flight demonstration required)
- Insurers may buy salvage services; but only if the mission falls within strict technical and financial guidelines.

The bottom line is that insurers will not be the driver for repair and resupply. Spacecraft builders may be driver's, but only if the customer wants it or it gives them the competitive edge.

#### Mike Leonard, Space Systems/Loral

Mr. Leonard discussed market characteristics, noting that there is over capacity in some segments. Alternative technologies and technology development are not the important issues - customer needs are the driver.

He noted that Intelsat transponders (400) have had zero failures over the planned lifetime of seven years. Thirteen of fifteen Intelsat V's achieved orbit. Nine Intelsat VII series satellites will be built.

Future geosynchronous satellites will have longer life (12 to 15 years). New Low Earth Orbiting comsats such as Global Star (a 48 satellite constellation in 6 planes at 1406Km altitude and 52° inclination) will follow a "replace rather than repair" philosophy.

Past history indicates that primary failure modes are TWTA's, electro thermal thrusters and gyros.

Service and resupply implies a modular spacecraft with accessible components. A concern is that the customer may not want extended life because of planned obsolescence and the financial advantage of a 10-year versus a 20-year depreciation. To be cost effective, geo-servicing missions must service multiple satellites. Because the target cost of LEO satellites is \$15M per spacecraft, it will be cheaper to replace rather than repair.

#### Jim Maley, NASA

TDRSS was not designed to be repaired or resupplied. To-date there have been 19 failures (15 traveling wave tubes and 4 busses). In the future, NASA will eliminate TWT's and move towards smaller spacecraft.

#### George Levin, NASA

Mr. Levin reviewed a study conducted by INTEC, under contract to NASA Headquarters, to determine the viability of In-Space repair and resupply. The approach was to:

- Review previous spacecraft failures.
- Forecast the number and estimated value of future spacecraft.
- Determine the price at which repair becomes an attractive alternative to replacement.
- Forecast the number of repair opportunities (extrapolate historical data).
- Examine the repair opportunities forecast from the perspective of a potential commercial salvage vehicle operator.

Historical data presented were:

- 328 satellites launched from 1980 to the present
- 64 experienced some type of failure
  - ascent to LEO, 21

- propulsion system failure, LEO to high energy orbit, 13
- spacecraft failure during checkout, 19
- operational failure, 11

The financial model had three options: repair, replace, do nothing. The replace option spreads the replacement cost over the "replace time" and then collects revenues for the full expected satellite lifetime. The repair option spreads repair cost over the "repair time", then collects revenues for the remainder of expected satellite lifetime less the repair time.

A typical example was:

- Replacement cost is \$150M over 3 years.
- Revenues are 100M \$/yr over a 10-year life.
- Discount rate is 7%.
- Repair time is one year.
- Replace success rate is 85% (historical data).
- Repair success rate is 80% (estimate).

The net present value of the replace option is \$356M. The break even repair mission cost is \$140M.

Over the next three years, we can expect about 36 spacecraft launches per year, worldwide (about 15 commercial missions per year). Based on historical data, there would be about 2.3 failures per year (total).

Mr. Levin stated that the results were reviewed with NASA and DoD upper management and with the aerospace industry with essentially no interest or commitment indicated in developing the repair capability.

Peter Stark, Consultant

Mr. Stark reviewed the results of his sensitivity analysis. His primary results for the same typical example discussed by Mr. Levin were:

- Doubling the repair time to two years reduces the repair break even cost by \$72.6M (to \$67.4M).
- Increasing the replace time to four years increases the repair break even cost by \$29.6M (to \$169.6M).
- Increasing the differential failure rate from 5 to 10% reduces the repair break even cost by \$32.6M (to \$107.4M).
- Increasing the discount rate by 1% reduces the repair break even cost by \$26.4M (to \$113.6M).

Bill Schick, KPMG Peat Marwick

Mr. Schick offered the following comments:

- The total market is 2.3 failures per year (average).
- Commercially insured spacecraft median cost is \$31.6M.
- Commercially uninsured spacecraft median cost is \$160M.
- Civil and DoD spacecraft median cost is \$150M - \$200M.

- There has been no interest demonstrated by customers in salvage or designing spacecraft for salvage.
- Building salvage-friendly features by owner requires prior demonstration of salvage technology.
- Operators generally want new technology rather than life extension; but, second and third hand operators may be there - obviously at reduced cost.



## **SESSION II**

### **Jack Koletty, EER, Inc.**

Jack gave a presentation of EER's SELV launch system family. He identified three primary systems:

- Space Systems
- Information Systems
- Training Systems

EER has had six launches to date out of White Sands. The longest part of the presentation was on the Conestoga (which means covered wagon) launch vehicle family. Main features of the Conestoga are: (1) continuous and flexible size selection for payloads from 500 to 4700 pounds ; (2) common motor emberfamilies for all configurations; and, (3) fairing design and range of standard lengths offer users a variety of size and access options. A video was presented which showed three development tests: (1) wind tunnel test; (2) engine firing test; and, (3) fairing separation test. They claim that they can launch a vehicle in 30 days, and the first launch is set for February 1994.

### **Larry Langston, Lockheed Missiles and Space Company**

Lockheed has directed the launching of more than 300 vehicles. Larry talked about the Lockheed Launch Vehicles (LLV). The LLV designs are based on Lockheed's experience with the Polaris SLBM. There are three LLV's that have capacities of 1, 2, and 4 tons. Lockheed's goal for first launch of the LLV1 is set for November 1, 1994. They do not have a payload yet for the November flight. He said that they are still on target for meeting the launch date, and that they want a payload by next month. The guidance, navigation, and control is being purchased from other contractors.

Pat Albert, Martin Marietta

Pat's presentation was on the Martin Marietta MSLS launch system. This vehicle is based on a converted Minuteman ICBM and can handle payloads of up to 800 pounds. One feature of the vehicle is that half the shroud can be easily removed and the payload accessed. The Minuteman vehicles are owned by the DoD and are only available to other U.S. government agencies. Hence, there is no reason for a commercial industry to come to Martin for a launch.

Chris Schade, Orbital Science Corporation

Chris talked primarily about Pegasus, with some comments on Taurus, too. Pegasus can handle payloads of up to 1000 pounds, with a launch price of \$8 - 12 million. The payload bay is 75 inches long and 46 inches in diameter. Pegasus is launched from an airplane allowing for twice the payload to be handled as with a ground-based launch. A video accompanied the presentation. The Taurus rocket is a ground-launched, modified Pegasus.

Mike Dobbs, ERIM/SPARC

Mike's talk was on the Space Automation and Robotics Center technology development program. His company has a Memorandum of Understanding with Langley and JSC. They are working on Rendezvous and Docking of a chaser vehicle with a target vehicle. They have combined autonomous rendezvous and docking on a Ranger system. They expect to fly the target vehicle in FY94 and the chaser vehicle in FY96. They are currently shopping for a launch vehicle.

Ralph Will, NASA Langley

Ralph discussed past and present robotics systems applicable to SELV's. He said that there is lots of technology available in robotics, but that none of the technology is specific, nor has it been flight tested. There have not been any flight tests because there is no customer yet. He commented that it must be shown that robotics meet or exceed the capabilities of the alternatives.

Dan Moerder, NASA Langley

Discussed current efforts in rendezvous and docking of two vehicles in space. The approach is to develop highly automated generic tools.

Ray Montgomery, NASA Langley

Mentioned that standardization of computers, software, devices, etc. is one of the most important issues to address.

Kevin Dutton, NASA Langley

Kevin presented some initial studies on GPS systems. One question that arose is the reliability of GPS. He responded that there are enough satellites so that at any time and any place, there are the necessary four satellites for position sensing.

Steve Thibault, CTA Launch Systems

Steve mentioned that CTA used to be International Microspace. His talk was on the CTA/ORBEX launch system. They were able to launch a vehicle 360 days after a contract at a cost of \$4 million. The corporate vision is to offer data services.

### **SESSION III**

#### **Bill Hohwiesner, Fairchild Space**

Mr. Hohwiesner began with a review of Fairchild's work in the in-space servicing area. This included development of tools and related technology for a variety of missions. Examples given were the interfaces placed on the Extreme Ultraviolet Explorer (EUVE) to enable a future servicing mission, the Solar Max servicing by Shuttle astronauts and the planned Hubble Space Telescope (HST) servicing mission.

Mr. Hohwiesner first reviewed the Solar Max mission, originally launched by the Shuttle in 1980 and then serviced in 1984. He described how the spacecraft was designed for an STS retrieval and how the subsystem modules were designed for on-orbit removal and replacement. For this mission, Fairchild developed the Module Service Tool, which is inserted into a latch on the modules to simultaneously remove the bolt holding them to the spacecraft bus and disconnect their electrical interfaces.

He later discussed on-orbit servicing by astronauts of a spacecraft not originally designed for servicing. In this mission, the thermal blanket was cut and an electrical box was replaced. A similar operation was later demonstrated on the ground using teleoperation.

Mr. Hohwiesner then discussed the Explorer class of spacecraft (such as EUVE). These are designed so that every module could be replaced without requiring EVA. Design details include:

- Removable high gain antenna.
- Removable main spacecraft modules.
- The Platform Equipment Deck (PED) contains six modules which can be removed on-orbit.
- The payload module is removable by removing three Acme screws which can be reached when the spacecraft is grappled by the RMS and docked to the shuttle.

He next described their work on the HST servicing with GSFC. This involved modifying the flight support system and building an ORU carrier and a Solar Array carrier. They also built a servicing tool which was miniaturized so that it could be placed on the end of the RMS arm.

Fairchild also has a "Servicer Aid" which is currently in validation. It can be mounted in the aft cargo bay of the shuttle and contains a 6 DOF force reflecting master arm. This arm can generate up to 500 lbs in zero gravity. The test article weighs 350 lbs and their goal is to have this reduced to 150 lbs plus 50 lbs for the electronics. This is completing flight qualification for the second HST servicing mission. The master arm will be mounted in the aft cargo area and reflects up to 21 lbs of force back to the operator. The slave arm can be adjusted in size depending upon the application. The arm lengths are interchangeable.

14 Mr. Hohwiesner stated that servicing could be a cost effective way of extending spacecraft life. The high cost of the servicing missions in the past was the result of the high costs of using the Space Shuttle. Fairchild has demonstrated teleoperated servicing operations in the lab which they believe offers the potential for low-cost spacecraft life extension

In the area of GPS, Mr. Hohwiesner explained that the RADCAL mission was using a \$12,000 Trimble receiver (as compared to the \$500,000 one on TOPEX) and that Fairchild is going to demonstrate relative navigation with GPS on shuttle mission STS-69. This is to be complemented by the proximity sensors developed by Tom Bryant's branch at MSFC. This mission will demonstrate station keeping around a three-point docking adapter.

A characteristic of many potential servicing missions is a failure to reach proper orbit. On this note, Mr. Hohweisner described a device developed by Thiokol under an IRAD to re-ignite a failed apogee kick motor. This device has been demonstrated.

Mr. Hohweisner provided further detail about EUVE apropos a servicing mission. An Earth-Pointing attitude was studied for the fluid resupply missions. They have shown that the EUVE

ACS can maintain attitude control in a single mode through the docking maneuver with up to a 1000 lb chase vehicle.

The 12 channel GPS system can be used to navigate within 500 meters before the laser sensors take over.

Mr. Hohweisner then discussed cost estimates for such a mission. Putting it together within a year would be difficult ; 1.5 years is more likely. The cooperative target servicer could easily be built for \$40 million or less. Probably, it could be built for less than \$30 million. The non-cooperative servicing mission would be in the \$40-50 million range, the main driver for this mission is the cost (at least \$5 million) for the high gain antenna. This excludes the launch vehicle costs.

Prof. Dave Akin, University of Maryland

Prof. Akin serves on the NASA telerobotic working group and presented his work and the status of the Ranger mission.

Prof. Akin's research in telerobotics began when he was at MIT. Under a grant from MSFC, his group conceptually designed the HFFT (Hybrid Free Flying Tele-robot) which provided a life support capsule for an astronaut who could operate the robotic systems on its exterior.

In 1990, Prof. Akin moved his research to the University of Maryland. A neutral buoyancy facility consisting of a 50 foot diameter water tank was made available there for his research.

At this point, the concept for the Ranger mission was formulated. It is designed to have the same servicing capability as an astronaut in a pressure suit and would be constrained to fit within the shroud of the Pegasus launch vehicle.

Following this initial feasibility study, Prof. Akin's group determined that this mission was possible as a flight experiment and set the ground rules for a flight demonstration to be flown in the first quarter of 1996 at a budget of less than \$ 6 million.

The objective of the flight experiment is to correlate experience in the neutral buoyancy facility with actual space operations.

As a high risk mission, Prof. Akin is willing to accept mission failure. For this reason, the tests will be phased, starting with simple operations which have lower inherent risk and then progressing to more difficult tests.

16 Prof. Akin then went into more detail about the design of the Ranger spacecraft. The section where the manipulators are attached is designed to minimize the frontal area so as to reduce the potential for interference with motion of the arms. The overall vehicle is sized to be roughly Human scale. Two dexterous manipulators are provided. Prof. Akin expanded on the studies showing that one-handed EVA is severely limited in its capabilities. Vision is provided by a stereo camera which can be maneuvered around the vehicle and its target.

More details were given on Ranger. The total mass was about 1000 lbs. Reaction wheels and batteries were the main drivers in mass. Approximately 400 lbs was allocated to computers and the manipulators. The power system had a 6kW peak capability with 1.5 - 2 kW average.

Ranger is planned to be launched into a high eccentricity orbit which would give four passes per day in which to communicate with the vehicle. It will be launched as a secondary payload with LAGEOS into a 5900 km altitude orbit.

The minimum criteria for mission success would be data on manipulator behavior in orbit. Further goals are to demonstrate some specific operations planned for servicing missions. The spent booster stage from Ranger's launch will be used as its target.



The end effectors are designed to be interchangeable. Approximately 20 lbs of force and 20 ft-lbs of torque can be applied through the end effector. The spacecraft will make a rigid grapple with the target using a passive grapple mechanism. The grapple is the only mechanism on Ranger which has friction brakes. The kinematics are such that no singularities are present within the workspace of the manipulators. Drive electronics for each joint are co-located with the drive motors themselves.

Prof. Akin then outlined some typical satellite servicing tasks to be demonstrated. These include: target acquisition, grappling (using a device designed for the EVA handrail), and refueling.

The Ranger mission is scheduled to last 30 days. After the first two weeks, all manipulators will be recalibrated. The video data generated will be stereo and color, with a data rate of 3 Mbits/sec. Commercial grade components are used throughout, avoiding Mil-Spec parts when possible. Once the upper stage is grappled, the chaser will never be disconnected.

Overall, this is planned to be a high risk mission in which the robotic core vehicle is designed so that should a failure occur, it could recover. This is done by avoiding critical single-string failures and making use of the extensive experience in the neutral buoyancy facility.

#### John O'Donnell-Oceaneering Space Systems (OSS)

Mr. O'Donnell began with a overview of Oceaneering's work in space systems. Currently they support the space station project at level II.

The primary business of the company, however, is in off-shore oil exploration. Oceaneering was started in 1965 and presently has 45 offices with headquarters in Houston, TX. The aerospace portion of their business began six years ago and was the result of their recognition that many techniques that they developed for undersea operations had space applications.

Their support to NASA is primary in EVA & Robotics.

Mr. O'Donnel then described hardware which has been developed for use on the space station and which has a heritage from manipulators developed originally by GE for undersea work. This hardware has undergone development testing for space station. He also described some neutral buoyancy testing which they have done including a Satellite Servicing System (SSS) developed by TRW.

Mr. O'Donnel then described some EVA-specific systems which have been developed and tested in the neutral buoyancy facility. One such technology is the Neutral Buoyancy Portable Life Support System (NBPLSS). This was developed to eliminate the difficulties involved when performing neutral buoyancy testing in which, in the past, two additional divers were required to maneuver all of the umbilicals which supply the pressure-suited astronaut. The (NBPLSS) provides these services autonomously eliminating the need for the umbilicals. This technology has had spin-offs into hazardous material handling and fire fighting applications.

Oceaneering has also developed the tools and tool box for the Hubble servicing mission.

In their operation of the neutral buoyancy facility at MSFC, the improvements which Oceaneering has implemented have extended the underwater time in suits to over six hours.

#### Davy Haynes, NASA LaRC/STIO

Mr. Haynes presented a series of candidate missions which he had identified from the history of launch failures, and then used these missions as guidance in conducting a parametric study addressing mission feasibility for launch performance within the range of typical SELV's.

His survey looked at five candidate missions, representing on-orbit spacecraft failures. These were: Arabsat 1A (AOCS failure); Insat 1C (power diode failure); Insat 1A (seal failure and loss

of fuel); Superbird (command error and loss of fuel); and, Palapa (Westar 6) (stranded in useless orbit).

From these candidates, Mr. Haynes defined a baseline mission for the study. For on-orbit repair, a distinction was made between restoration, replacement, and supplement. The other generic missions identified were: de-orbit and disposal; refueling; payload delivery and recovery; retrieval for repair; and, reboost.

These missions were further broken down into the types of orbits which must be reached, so as to provide a comparison for the mass-to-orbit performance of available SELV's. There are three ranges of orbits of interest. The first is Low Earth Orbit (LEO), generally altitudes up to 800 km. This will include the Hubble space telescope, Earth Observing System, the Nimbus series, and anything which was originally designed to be serviced by the Space Shuttle. The second is Medium Earth Orbit (MEO), up to 20,000 km, and reachable with a spacecraft mass of 500 to 1000 kg. The Global Positioning System (GPS) would be classified into this category. The third is Geosynchronous Orbit (GEO), specifically at an altitude of 36,000 km and an inclination of 0 degrees. This is the orbital location of most present day telecommunications satellites.

It was assumed that the basic servicer, repair, and resupply hardware would be standard 'kits' designed for general missions which could be provided on short notice when the need arises, following a 'ship and shoot' delivery philosophy. Within such a framework, the individual development time for a specific mission would be minimized.

For GEO missions, refuel or boost to a higher orbit for disposal requires only 10's of kg of propellant (within the capability of SELV's).

Reboost was evaluated assuming a 200 km circular orbit, a 290 - 300 sec specific impulse and a 2000 kg payload. It was found that with a 0.8 mass fraction, a 850 kg spacecraft can be put into GEO. This would include the spacecraft as well as the Apogee Kick Motor.

In the refueling scenario, the same spacecraft bus could be used for either a GEO or a LEO mission due to the similar requirements.

Mr. Haynes' conclusion was that the performance of available SELV's is sufficient for most LEO, some MEO and only refuel, disposal, and small and simple repair or supplementation at GEO.

## **SESSION IV**

### **Synthesis and Government Role**

The discussions in this session started with the request for additional missions that may not have been identified in the mission taxonomy presented by Davy Haynes. It was generally accepted that all apparent missions had been identified, with only a few additions offered from the floor. It was suggested that a LEO mission comprised of a servicer satellite capable of resupply of expendables or repair for a constellation of satellites should be added. Furthermore, the mission of boosting a stranded satellite from a useless transfer orbit, while captured in Mr. Haynes' categories, deserved particular emphasis due to the high payoff attending repair. This is particularly true for otherwise healthy communication satellites trapped in unintended geostationary transfer orbits.

Mr. Haynes expressed an opinion that rescue of such satellites may be outside the performance capabilities of SELV's. This proposition was discussed with the suggestion that analysis would probably clarify the issue.

The workshop was then asked to prioritize the missions in terms of financial impact, technology readiness, and practicality. Very little was developed with regard to the latter two categories, other than to note that most of the technology is currently available to do the missions, given the proper "design for servicing." Some other missions can possibly be done, but they must be approached on an individual basis.

With respect to financial impact, Mr. Jeff Cassidy noted that the great bulk of the market was in the highly accessible LEO orbits. Mr. Cassidy further noted that while the market was in LEO, these are virtually all uninsured Government satellites, and consequently of no interest to the insurers. Mr. Jack Koletty of EER noted that with the current government emphasis on commercialization such as "data buys," there was the very high likelihood that some of these LEO assets may find themselves in the hands of private owners. Mr. Koletty further asked whether it was Mr. Cassidy's understanding that these commercial space assets would or

would not be insured. Mr. Cassidy allowed that he believed that, indeed, the assets would be insured and that the insurance companies would then be interested to see what might be proposed vis-a-vis servicing.

Mr. Cassidy noted to the group that while many assets might well benefit from servicing, most of these were not insured. While servicing of uninsured assets is obviously of no interest to his company, that was most probably not the case with their uninsured owners (the Government).

As far as the Government role and the protection of proprietary rights in the presence of public expenditures was concerned, the group felt that both taxpayers and companies could easily have their interests accommodated. It was asked, was this true even in the case of flight projects with multiple companies? The private company representatives agreed that sufficient safeguards were available and already in practice.

As far as the Government role is concerned, the company representatives agreed that access to Government facilities was important and that cooperative activities would be important in developing an In-Space Operations industry. Nevertheless, the role of the Government in providing seed money and particularly some flight demonstrations was acclaimed as the most important single thing to be done. The experience of the undersea oil drilling industry backs this notion in that early technology efforts by the Government served as catalyst for an industry that is now indispensable in undersea operations.

It was suggested by Mr. Larry Langston of Lockheed that the Government might wish to make a CBD announcement asking for information from companies related to developing a broad range of suggestions with respect to ways the Government can more effectively work with private industry.

At 3:00 pm, Dr. Katzberg thanked the participants for their enthusiastic participation, noted the intention of producing a Proceedings, and the intention of keeping the group informed of any follow-on activities. That done, Dr. Katzberg adjourned the workshop.

# **SESSION I**





# **Summary of the SELV-Based In-Space Operation Workshop**

## **October 18-19, 1993**

### **Hampton, VA**

#### **SESSION I**

Jeff Cassidy, U.S. Aviation Underwriters, Inc.

There was a wide fluctuation in insurance rates and capacity between the mid-1960's and the mid-1980's. Since that time, the insurance market has been stable with a current market capacity of \$300M- \$350M. Despite losses in the early 1990's, rates have remained relatively constant.

Property coverage is divided into three phases:

- Launch
- Initial on-orbit checkout
- On-orbit operations (through end of satellite life)

Rates and insurability are based on projected reliability from the spacecraft provider plus past experience.

In regards to insuring Space Repair, Logistics and Salvage Missions, Mr. Cassidy noted:

- Insurance has been available for SELV missions.

- Concerns are:
  - Technical complexity
  - Hardware performance history
  - Testing and Quality Control Approach
  - Company qualifications (including subcontractors)
  - Loss criteria under the policy
  - Perceived probability of success
- It is important to involve the insurers early in the design process for new systems.
- Insurance is only one element of risk management (e.g., reliability, redundancy, etc.).
- Each mission will be underwritten and priced separately.
- Terms and conditions will be tailored to the risks and requirements of the mission.

26

Specifically with respect to Salvage, Mr. Cassidy noted:

- After claims payment, insurers often have salvage rights.
  - (Westar 6 and Palpa B2 are the best examples)
- To obtain salvage, insurers may:
  - Allow insured to operate (in degraded mode); insurer receives part of revenues
  - Take title and sell
  - Repair and sell
- Repair or resupply capability may enhance the value of salvage.

- On-orbit salvage is appealing if:
  - Costs are low in comparison to gain
  - High probability of success
  - Technically sound approach with low risk to healthy satellite subsystems
  - Flight proven (flight demonstration required)
- Insurers may buy salvage services; but only if the mission falls within strict technical and financial guidelines.

The bottom line is that insurers will not be the driver for repair and resupply. Spacecraft builders may be driver's, but only if the customer wants it or it gives them the competitive edge.

#### Mike Leonard, Space Systems/Loral

Mr. Leonard discussed market characteristics, noting that there is over capacity in some segments. Alternative technologies and technology development are not the important issues - customer needs are the driver.

He noted that Intelsat transponders (400) have had zero failures over the planned lifetime of seven years. Thirteen of fifteen Intelsat V's achieved orbit. Nine Intelsat VII series satellites will be built.

Future geosynchronous satellites will have longer life (12 to 15 years). New Low Earth Orbiting comsats such as Global Star (a 48 satellite constellation in 6 planes at 1406Km altitude and 52° inclination) will follow a "replace rather than repair" philosophy.

Past history indicates that primary failure modes are TWTA's, electro thermal thrusters and gyros.

Service and resupply implies a modular spacecraft with accessible components. A concern is that the customer may not want extended life because of planned obsolescence and the financial advantage of a 10-year versus a 20-year depreciation. To be cost effective, geoservicing missions must service multiple satellites. Because the target cost of LEO satellites is \$15M per spacecraft, it will be cheaper to replace rather than repair.

#### Jim Maley, NASA

TDRSS was not designed to be repaired or resupplied. To-date there have been 19 failures (15 traveling wave tubes and 4 busses). In the future, NASA will eliminate TWT's and move towards smaller spacecraft.

#### George Levin, NASA

Mr. Levin reviewed a study conducted by INTEC, under contract to NASA Headquarters, to determine the viability of In-Space repair and resupply. The approach was to:

- Review previous spacecraft failures.
- Forecast the number and estimated value of future spacecraft.
- Determine the price at which repair becomes an attractive alternative to replacement.
- Forecast the number of repair opportunities (extrapolate historical data).
- Examine the repair opportunities forecast from the perspective of a potential commercial salvage vehicle operator.

Historical data presented were:

- 328 satellites launched from 1980 to the present
- 64 experienced some type of failure
  - ascent to LEO, 21

- propulsion system failure, LEO to high energy orbit, 13
- spacecraft failure during checkout, 19
- operational failure, 11

The financial model had three options: repair, replace, do nothing. The replace option spreads the replacement cost over the "replace time" and then collects revenues for the full expected satellite lifetime. The repair option spreads repair cost over the "repair time", then collects revenues for the remainder of expected satellite lifetime less the repair time.

A typical example was:

- Replacement cost is \$150M over 3 years.
- Revenues are 100M \$/yr over a 10-year life.
- Discount rate is 7%.
- Repair time is one year.
- Replace success rate is 85% (historical data).
- Repair success rate is 80% (estimate).

The net present value of the replace option is \$356M. The break even repair mission cost is \$140M.

Over the next three years, we can expect about 36 spacecraft launches per year, worldwide (about 15 commercial missions per year). Based on historical data, there would be about 2.3 failures per year (total).

Mr. Levin stated that the results were reviewed with NASA and DoD upper management and with the aerospace industry with essentially no interest or commitment indicated in developing the repair capability.

Peter Stark, Consultant

Mr. Stark reviewed the results of his sensitivity analysis. His primary results for the same typical example discussed by Mr. Levin were:

- Doubling the repair time to two years reduces the repair break even cost by \$72.6M (to \$67.4M).
- Increasing the replace time to four years increases the repair break even cost by \$29.6M (to \$169.6M).
- Increasing the differential failure rate from 5 to 10% reduces the repair break even cost by \$32.6M (to \$107.4M).
- Increasing the discount rate by 1% reduces the repair break even cost by \$26.4M (to \$113.6M).

30

Bill Schick, KPMG Peat Marwick

Mr. Schick offered the following comments:

- The total market is 2.3 failures per year (average).
- Commercially insured spacecraft median cost is \$31.6M.
- Commercially uninsured spacecraft median cost is \$160M.
- Civil and DoD spacecraft median cost is \$150M - \$200M.

- There has been no interest demonstrated by customers in salvage or designing spacecraft for salvage.
- Building salvage-friendly features by owner requires prior demonstration of salvage technology.
- Operators generally want new technology rather than life extension; but, second and third hand operators may be there - obviously at reduced cost





**SPACE REPAIR AND SALVAGE**

**INSURANCE INDUSTRY ROLE**

**OCTOBER 18, 1993**

**JEFFREY S. CASSIDY**

**UNITED STATES AVIATION  
UNDERWRITERS, INC.**

# OVERVIEW

---

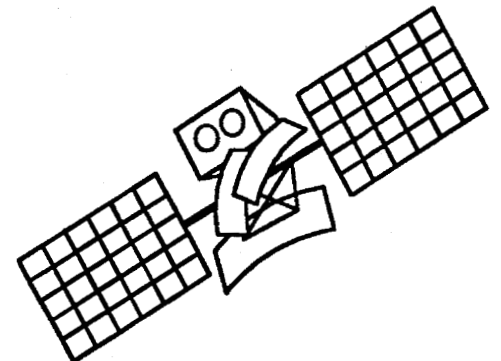
- **Space Insurance Industry**

- **USAIG**

- **Insuring Space Repair, Logistics and Salvage Missions**

- **Insurers as Buyers of Space Salvage Services**

***USAIG***

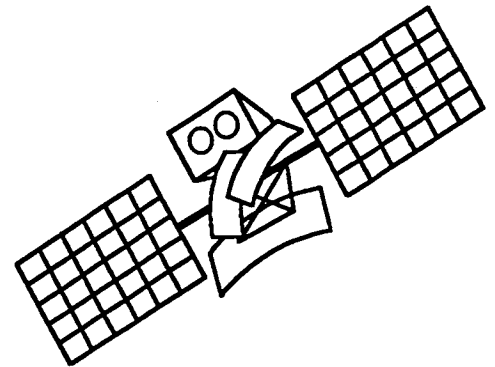


# SPACE INSURANCE INDUSTRY

---

- **First launch coverage placed in 1965**
  - » Early Bird satellite launch
  - » USAIG provided coverage
- **Wide fluctuations in rates and insurance capacity from late-1960's through mid-1980's**

*USAIG*

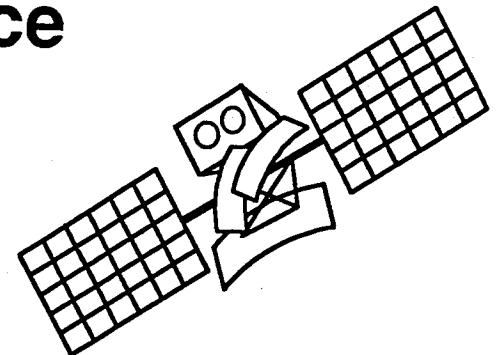


# SPACE INSURANCE INDUSTRY

---

- **Space Insurance market has been stable since mid-1980's**
  - » Rates down from mid-1980's high
  - » Capacity much higher than mid-1980's low
  - » Both rates and capacity have remained stable in spite of unprecedented recent losses
- **USAIG is one of the leading space insurers worldwide**

***USAIG***

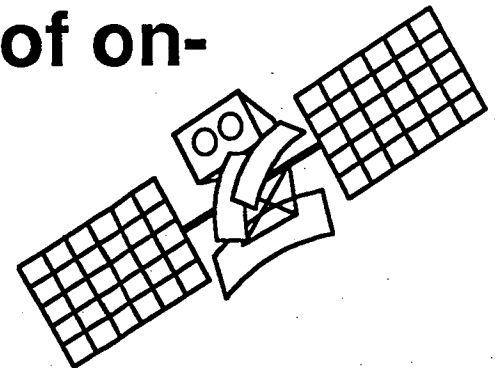


# PROPERTY COVERAGES

---

- **Launch – Coverage of launch vehicle and satellite from ignition to orbit**
- **Initial On-Orbit Checkout – Coverage from separation of satellite from launch vehicle through its in-orbit testing**
- **On-Orbit Operations – Coverage of on-orbit operations through end of satellite life**

*USAIG*



# OVERVIEW

---

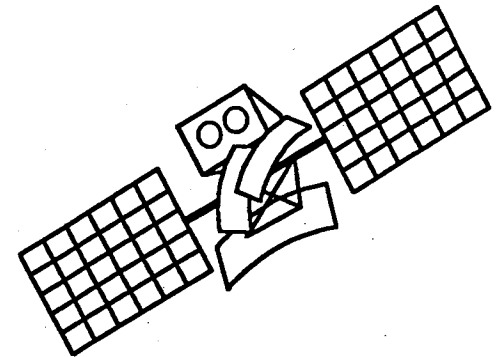
- **Space Insurance Industry**

- **USAIG**

- **Insuring Space Repair, Logistics and Salvage Missions**

- **Insurers as Buyers of Space Salvage Services**

***USAIG***

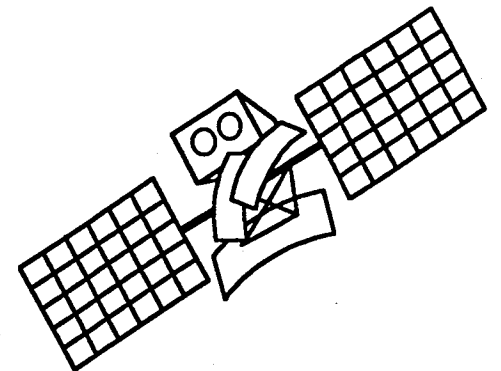


# UNITED STATES AIRCRAFT INSURANCE GROUP (USAIG)

---

- Group of insurance companies which pool capacity to insure aviation and space risks
- Pool is managed by United States Aviation Underwriters, Inc.
- Separate pool formed in 1981 specifically for space insurance

*USAIG*

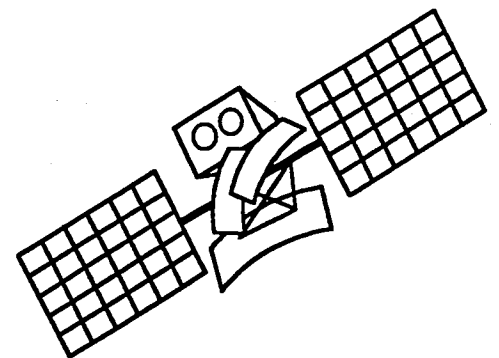


# USAIG INSURANCE COVERAGE

---

- General Aviation property damage and liability
- Aviation product liability
- Airline property damage and liability
- Aviation Workers Compensation
- Satellite launch and in-orbit coverage

*USAIG*





# OVERVIEW

---

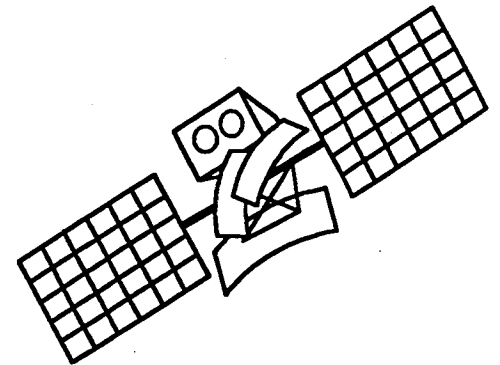
- Space Insurance Industry

- USAIG

- Insuring Space Repair, Logistics and Salvage Missions

- Insurers as Buyers of Space Salvage Services

*USAIG*



# INSURANCE FOR SELV MISSIONS

---

- Insurance has been available for many new space systems
- USAIG has insured many small ELV's and non-traditional risks:

Pegasus

Joust

Consort

Rosat

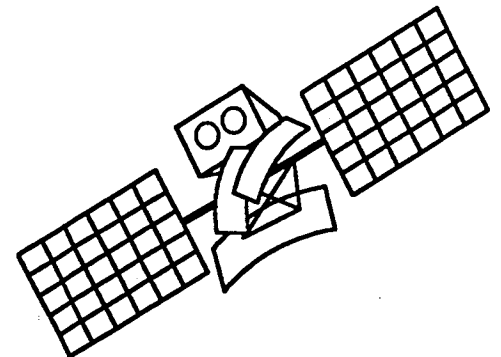
Orbcomm

MDAC Electrophoresis

Healthsat

Freja

**USAIG**



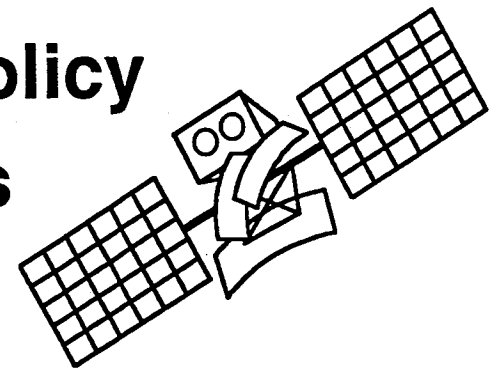
# UNDERWRITING CONCERNS FOR SELV REPAIR MISSIONS

---

Availability and cost of insurance for SELV repair missions will be driven primarily by the:

- Technical complexity of mission
- Performance history of all hardware
- Testing and quality control approach
- Qualifications of company performing the mission
- Loss Criteria under insurance policy
- Perceived probability of success

*USAIG*

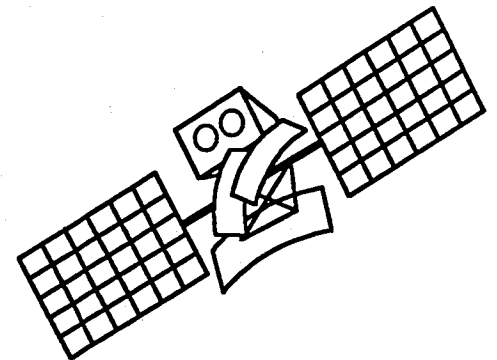


# UNDERWRITING CONCERNS FOR SELV REPAIR MISSIONS

---

- Each individual SELV repair mission (or like group of missions) will be underwritten and priced separately
- Each insurance policy's terms and conditions will be tailored to the risks and requirements of a specific SELV mission

**USAIG**

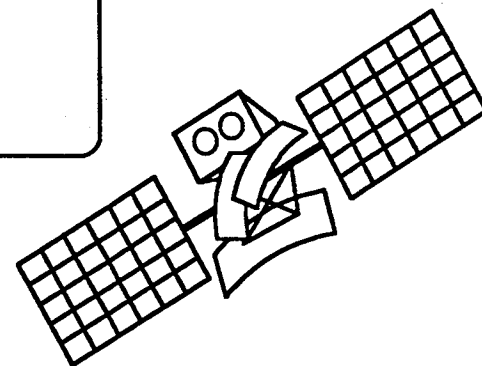


# OVERVIEW

---

- Space Insurance Industry
- USAIG
- Insuring Space Repair, Logistics and Salvage Missions
- Insurers as Buyers of Space Salvage Services

*USAIG*

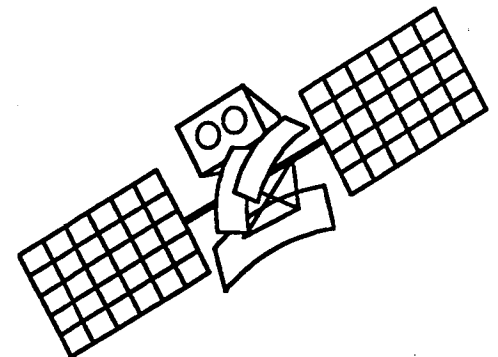


# SALVAGE SERVICE BACKGROUND

---

- Upon payment of a claim under an insurance policy, insurers often obtain the right to salvage
- Salvage in space insurance has been limited (e.g. Westar 6, Palapa B2)

**USAIG**

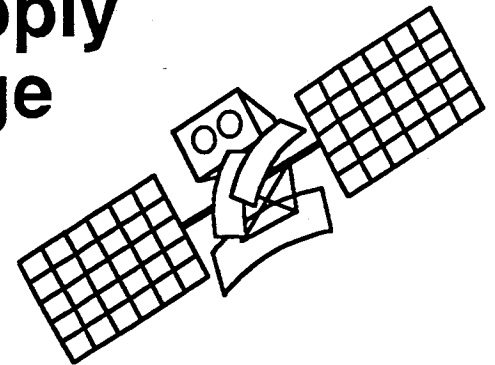


# SALVAGE SERVICE BACKGROUND

---

- **To obtain salvage, Insurers may:**
  - » **Allow Insured to operate satellite and receive a portion of revenue derived after failure; or**
  - » **Take title to failed satellite and find a buyer**
  - » **Repair the satellite?**
  
- **In selected cases repair or resupply may enhance the value of salvage to insurers**

*USAIG*

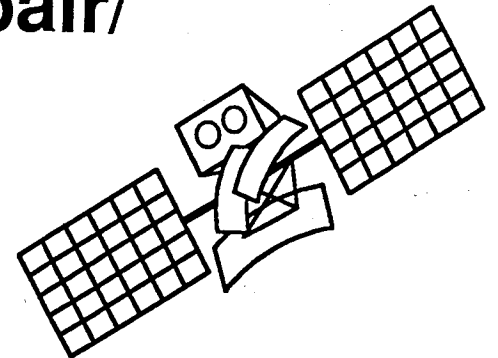


# SALVAGE SERVICE ATTRACTIVENESS

---

- On-orbit salvage will only be appealing if :
  - » Low cost in comparison to potential gain
  - » High probability of success
  - » Demonstrated technically sound
  - » Flight-proven
  
- Satellite design could enable repair/  
resupply missions

*USAIG*



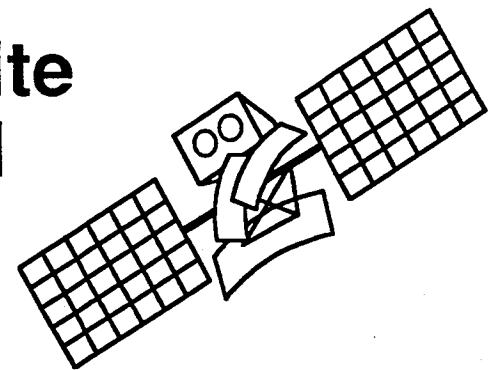


# SALVAGE SERVICE ATTRACTIVENESS

---

- **Satellite location/failure modes must be such that repair/resupply is technically feasible**
  - » **Capabilities of salvage systems are untested**
  - » **Many (most?) in-orbit failures would not be candidates for repair**
- **Risk of damage to healthy satellite subsystems must be considered**

*USAIG*

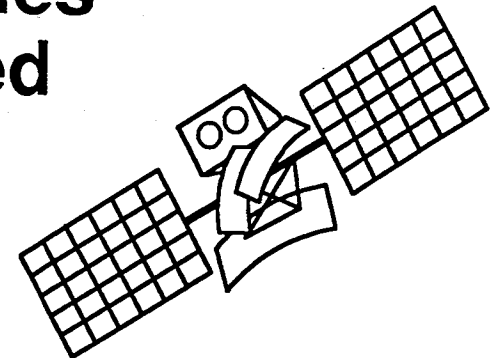


# SALVAGE SERVICE ATTRACTIVENESS

---

- Shuttle is not a commercially viable salvage option
  - » Most insured satellites not in Shuttle orbit
  - » Cost of Shuttle mission/services prohibitive unless subsidized as in past
- Insurance industry will likely require a flight demonstration of capabilities before committing to SELV-based repair missions

*USAIG*

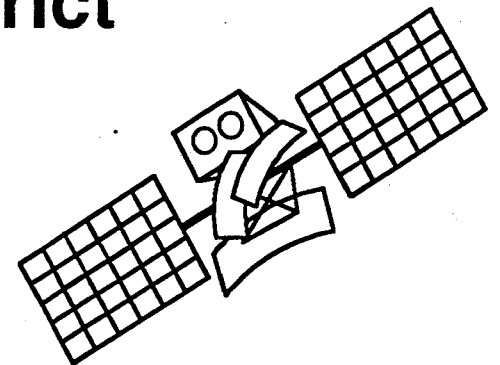


# SUMMARY

---

- **USAIG has insured many small ELV's and non-traditional space systems**
- **Depending on the technical and coverage characteristics, insurance may be available for SELV salvage missions**
- **Insurers may buy salvage services, but only if the mission falls within strict technical/financial guidelines**

***USAIG***





***SELV In -Space Operations  
Workshop***

***October 18, 1993***



# Satellite Experience

---

- 36 years in space activities
- SS/L has built and launched 77 spacecraft. (The Alliance total exceeds 120 spacecraft.)
- 68 spacecraft have successfully achieved their intended orbit
- 83% of the spacecraft have met or exceeded the design life
- 7 launch vehicle failures and 2 Apogee Motor failures
- 485 Years of orbital experience
- 28 current operational orbiting spacecraft

# Background Statistics

---

- An average commercial satellite system will be 45% subcontracted
- Complexity of spacecraft has increased dramatically over the last several years
  - 50,000 electrical piece parts today vs. 20,000 for early CS and NATO spacecraft
  - Required mission lifetime has increased from 3 years (NATO II) to 10 - 15 years
  - Intelsat VII equipment is designed for 16.4 to 22.5 years
- In spite of increases in complexity and mission life requirements, spacecraft are statistically continuing to meet mission requirements

56



# Anomalous Behavior

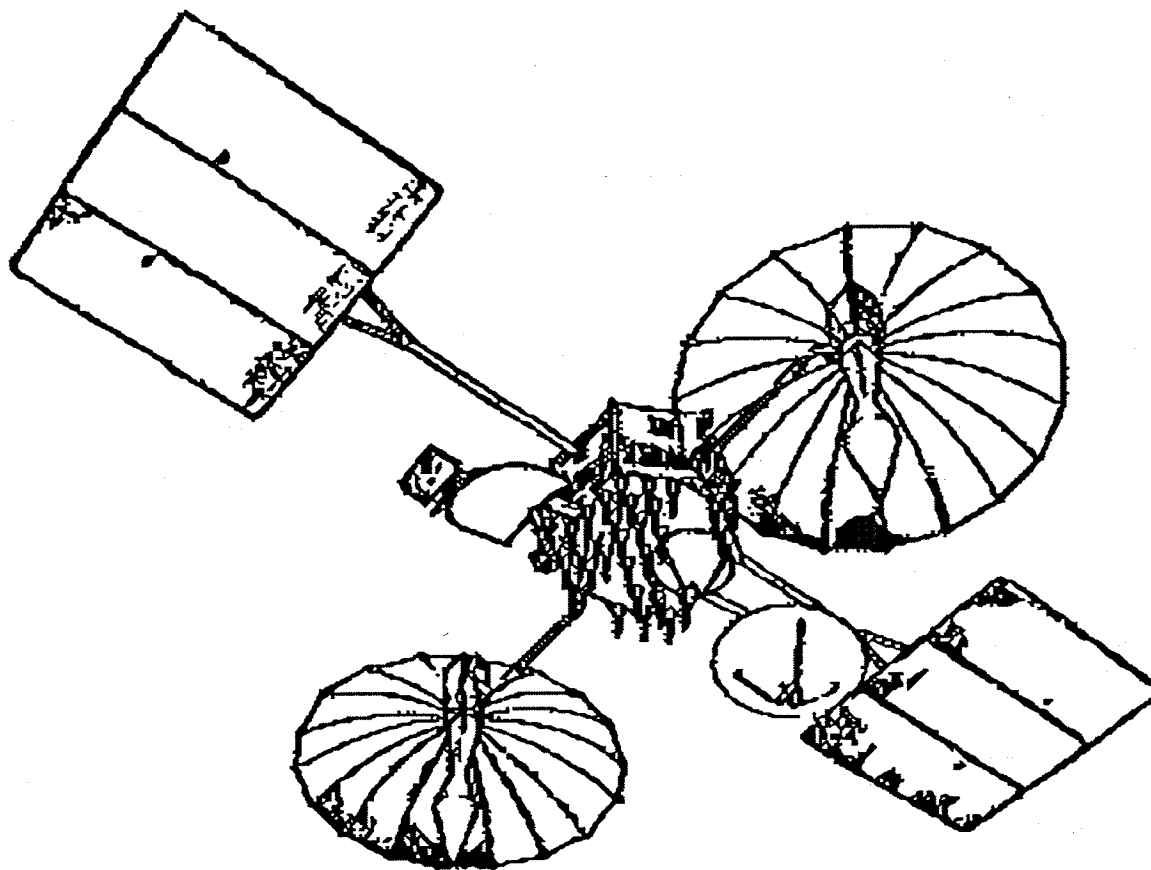
---

- An observation is that, “with the exception of TWTA,s, electrothermal thrusters, and gyros, there seems to be little wear out failure within the design life of basic subsystems”
- SS/L collects anomaly and failure data from a multitude of sources

## **Service and Resupply**

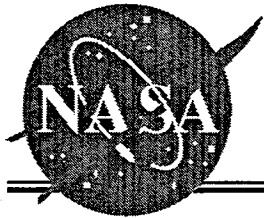
---

- **Candidate Service and/or Resupply (S/R) equipment (Implies modular spacecraft)**
  - **Batteries**
  - **Solar Panels**
  - **Accessible Electronic Components**
  - **Propulsion Components / Fuel**
- **CAVEAT**
  - **User (Customer) may not desire extended life system**
    - **Planned obsolescence**
    - **Financial Advantage (10 vs. 20 year depreciation schedule)**
- **Commercial market is driven not by technology as much as by customer needs**

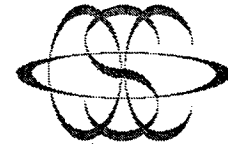


# *Space Network*

*Office of Space Communications*



# OFFICE OF SPACE COMMUNICATIONS



Office of Space Communications

**ASSOCIATE ADMINISTRATOR**  
**CHARLES T. FORCE**

**DEPUTY ASSOCIATE ADMINISTRATOR**  
**JERRY J. FITTS**

**REPRESENTATIVE IN SPAIN**  
**ANTHONY CARRO**

**REPRESENTATIVE IN AUSTRALIA**  
**GEORGE ANKRUM**

**PROGRAM  
INTEGRATION  
DIVISION**

**DAVID HARRIS**

**SPACE  
NETWORK  
DIVISION**

**EUGENE FERRICK**

**GROUND  
NETWORKS  
DIVISION**

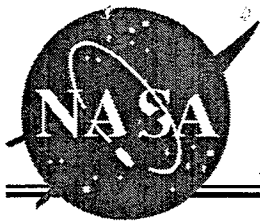
**ROBERT HORNSTEIN**

**COMMUNICATIONS AND  
DATA SYSTEMS  
DIVISION**

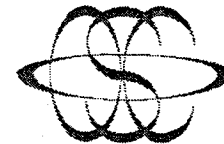
**CHARLES FUECHSEL**

**ADMINISTRATION AND  
RESOURCES  
MANAGEMENT  
DIVISION**

**RONALD DAPICE**

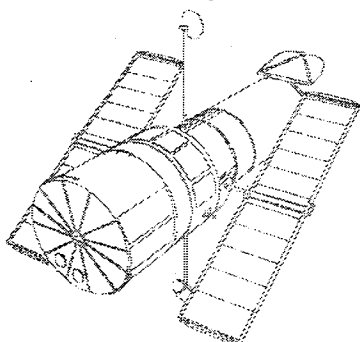


# SPACE NETWORK



Office of Space Communications

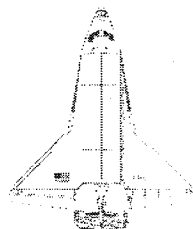
- THE TRACKING AND DATA RELAY SATELLITE SYSTEM (TDRSS) AND SUPPORTING FACILITIES PROVIDE NEARLY CONTINUOUS INTERFACE TO COMMUNICATE WITH AND CONTROL MOST NASA NEAR-EARTH ORBITAL MISSIONS
- THE SPACE NETWORK REPLACES THE SERVICES PROVIDED BY THE GROUND BASED TRACKING NETWORK (GSTDN)



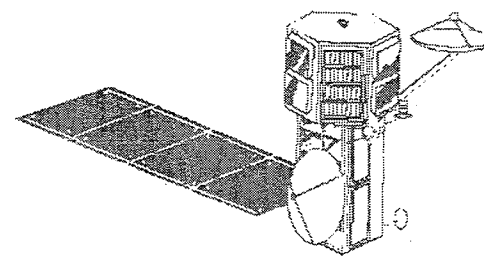
HUBBLE SPACE  
TELESCOPE



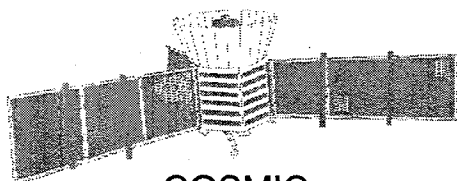
SPACE STATION



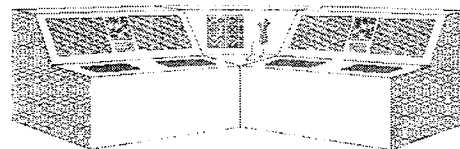
SPACE SHUTTLE



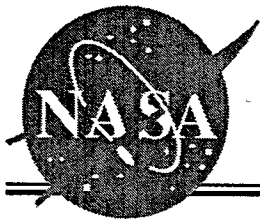
OCEAN  
TOPOGRAPHY  
EXPERIMENT



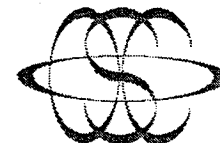
COSMIC  
BACKGROUND  
EXPLORER



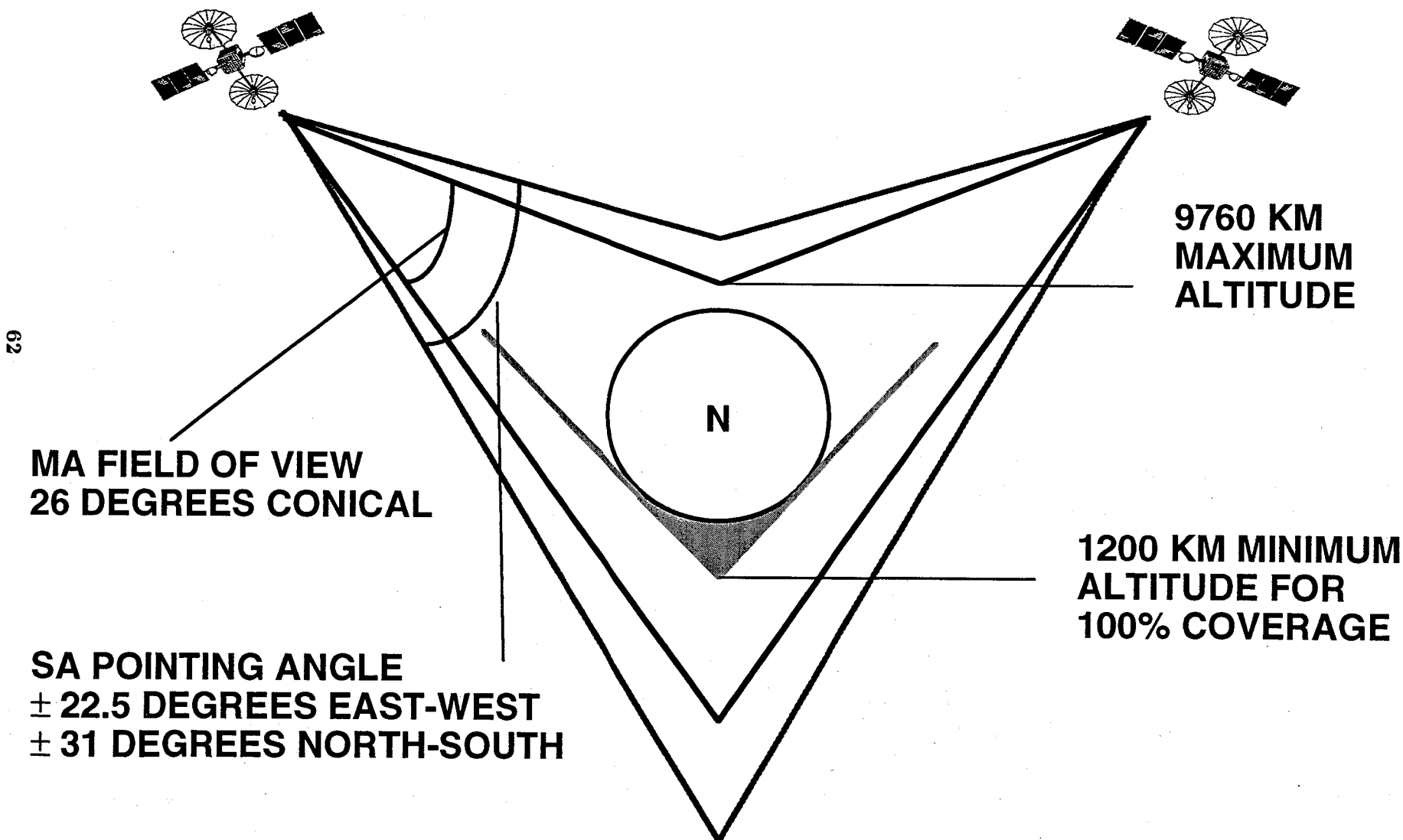
CONTROL CENTERS

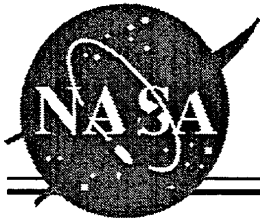


# ZONE OF EXCLUSION

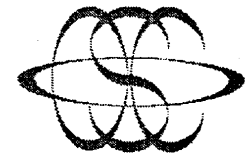


Office of Space Communications

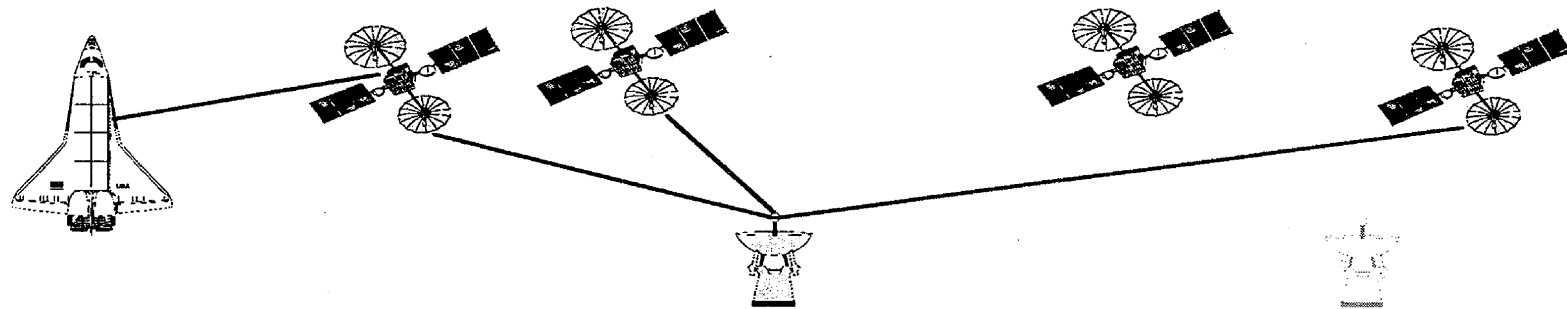




# SPACE NETWORK CONFIGURATION



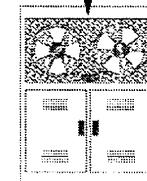
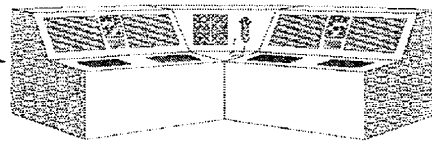
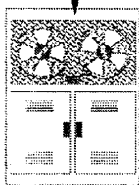
Office of Space Communications



CACIQUE

DANZANTE  
IN DEVELOPMENT

NASCOM



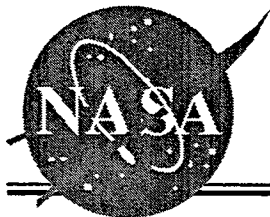
FLIGHT DYNAMICS  
FACILITY

NETWORK CONTROL  
CENTER (NCC)

CUSTOMER PROJECT OPS  
CONTROL CENTERS  
(POCCS)

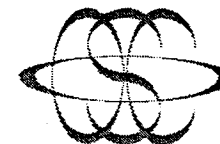
CUSTOMER DATA  
PROCESSING AND  
ARCHIVES

GSFC



## SPACE NETWORK

# PRINCIPAL CUSTOMERS



Office of Space Communications

### CURRENT

SSP — SPACE SHUTTLE PROGRAM  
COBE — COSMIC BACKGROUND EXPLORER  
ERBS — EARTH RADIATION BUDGET SATELLITE  
EUVE — EXTREME ULTRAVIOLET EXPLORER  
GRO — GAMMA RAY OBSERVATORY  
HST — HUBBLE SPACE TELESCOPE  
LANDSAT  
UARS — UPPER ATMOSPHERE RESEARCH SATELLITE  
TOPEX — OCEAN TOPOGRAPHIC EXPERIMENT

### FUTURE

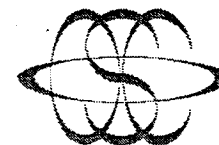
XTE — X-RAY TIMING EXPLORER  
SSF — SPACE STATION ALPHA  
TRMM — TROPICAL RAINFALL MEASUREMENT SYSTEM  
EOS — EARTH OBSERVING SYSTEM  
AXAF — ADVANCED X-RAY ASTROPHYSICS FACILITY





## *SPACE NETWORK*

# **GROUND TERMINALS**



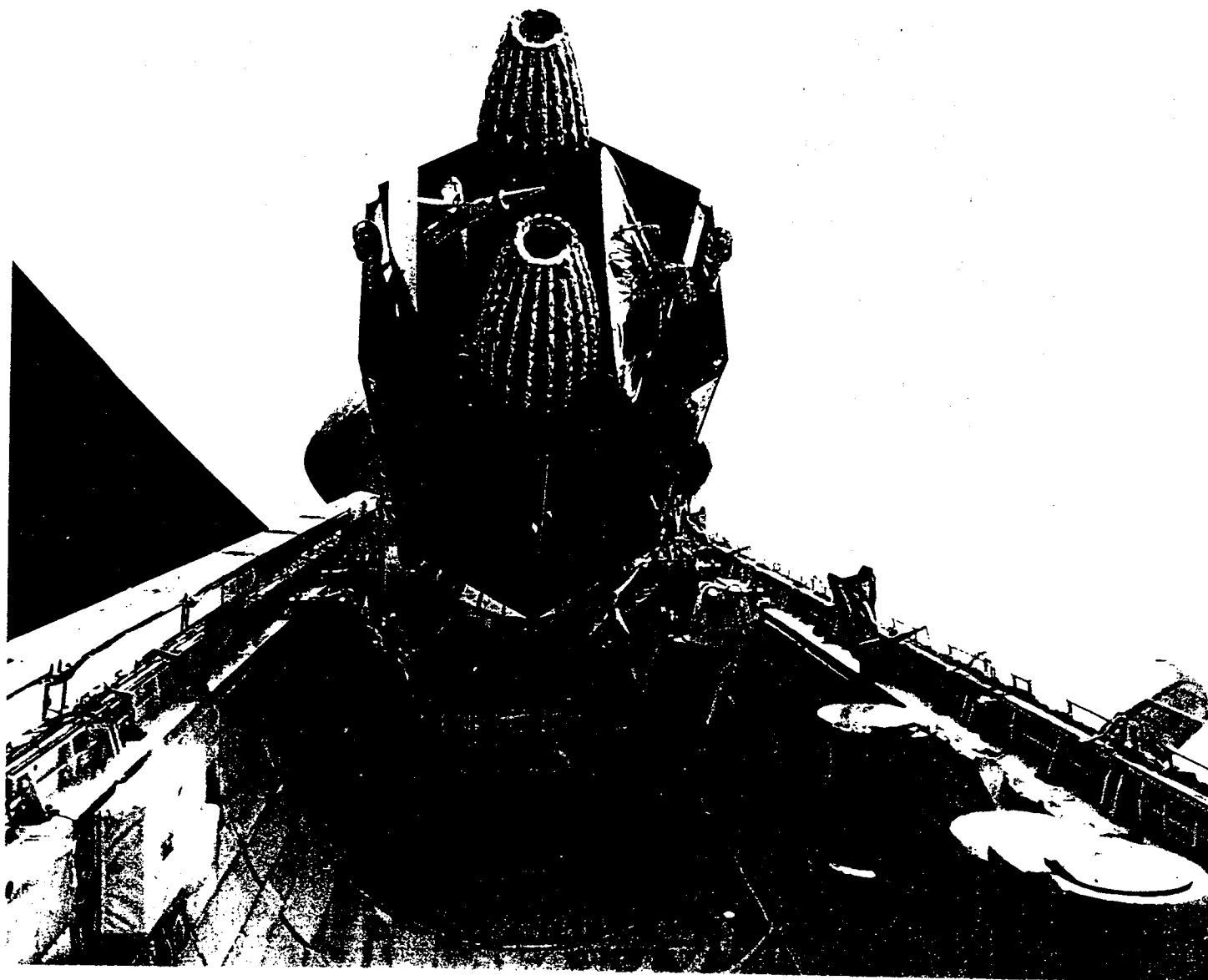
Office of Space Communications

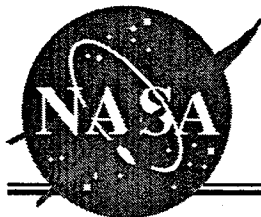
- CACIQUE IS DESIGNED TO SUPPORT TWO OPERATIONAL SATELLITES AND A BACKUP SATELLITE AND TO PROVIDE TT&C SERVICE FOR TWO SPARES
- DANZANTE IS SCHEDULED TO START OPERATIONS SEPTEMBER 1994
- CACIQUE WILL BE UPGRADED TO DANZANTE'S CONFIGURATION BY OCTOBER 1995
- THE COMBINED STATION COMPLEX WILL BE ABLE TO OPERATE UP TO SIX TDRS SPACECRAFT

# WHITE SANDS GROUND TERMINAL (WSGT)

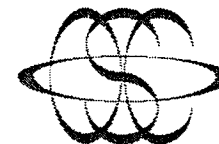


# TDRS DEPLOYMENT





# SPACE NETWORK TRACKING AND DATA RELAY SATELLITE (TDRS)



Office of Space Communications

4.9 METER ANTENNA  
(K/S BAND SINGLE ACCESS)

C-BAND ANTENNA  
(COMMERCIAL COVERAGE)

SOLAR ARRAY

S-BAND  
OMNIDIRECTIONAL  
ANTENNA

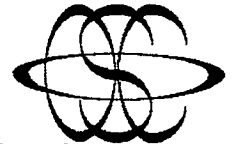
SOLAR SAIL

2.0 METER K-BAND SGL  
ANTENNA

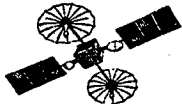
S-BAND PHASED ARRAY  
(MULTIPLE ACCESS SERVICE)



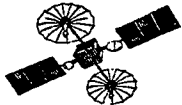
# SPACE NETWORK TDRS LAUNCH HISTORY AND SCHEDULE



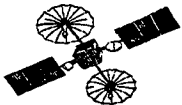
Office of Space Communications



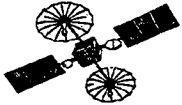
TDRS-1 LAUNCHED APRIL 1983, DEGRADED CAPABILITY



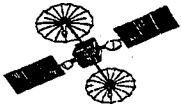
TDRS-2 LOST IN CHALLENGER ACCIDENT, JANUARY 1986



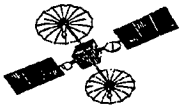
TDRS-3 LAUNCHED SEPTEMBER 1988, DEGRADED CAPABILITY



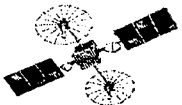
TDRS-4 LAUNCHED MARCH 1989, OPERATIONAL



TDRS-5 LAUNCHED AUGUST 1991, OPERATIONAL

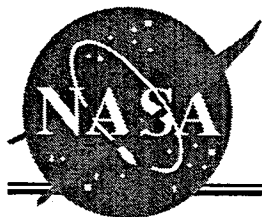


TDRS-6 LAUNCHED JANUARY 1993, PASSIVE BACKUP

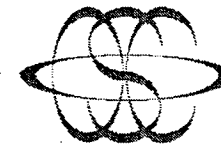


TDRS-7 IN CONSTRUCTION, PLANNED MID 1995 LAUNCH

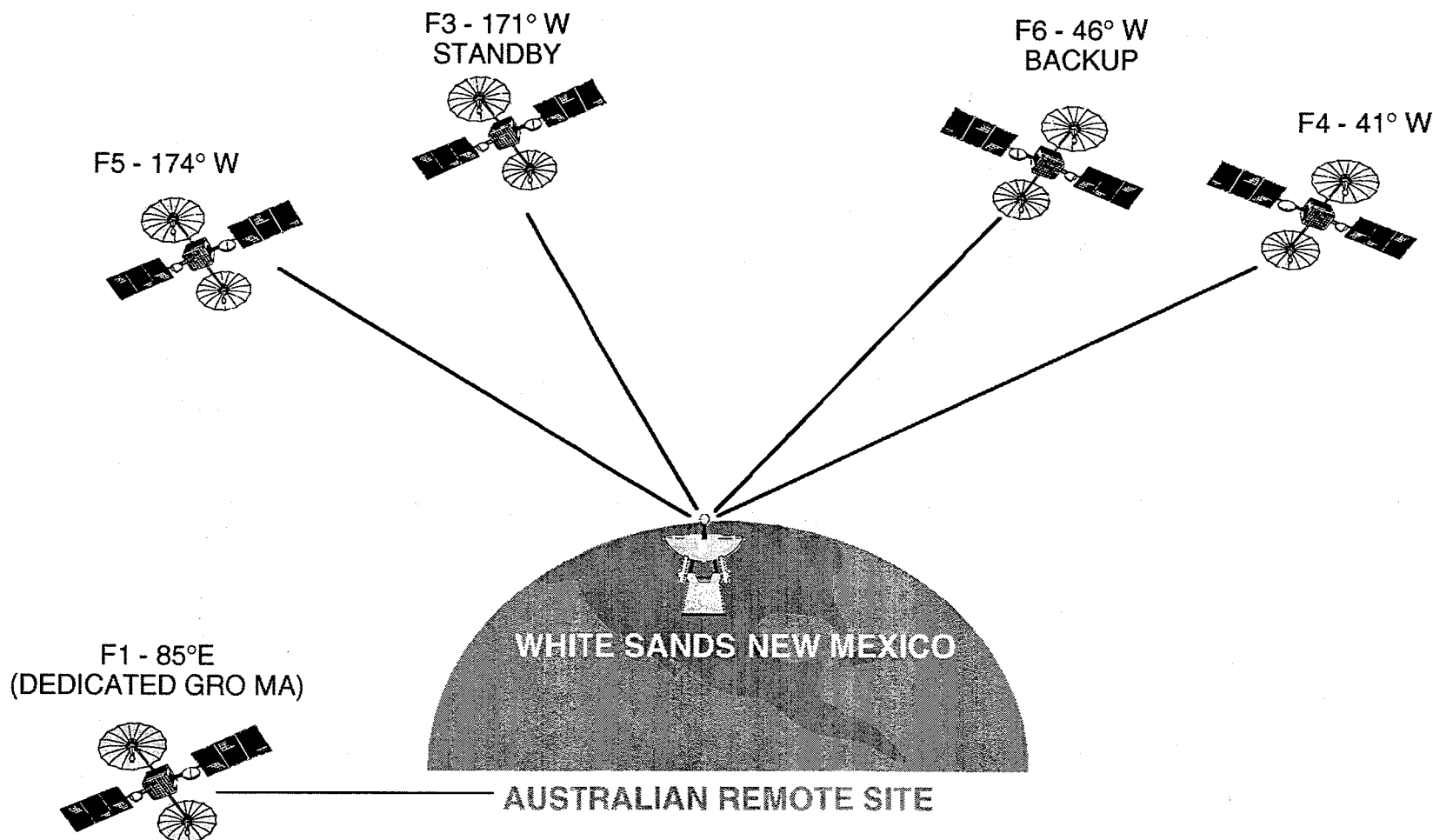
TDRSS REPLENISHMENT IN PROCESS WITH  
RFP RELEASE FOR THREE FOLLOW-ON  
SPACECRAFT SCHEDULED FOR FY 1994



# SPACE NETWORK FUTURE SPACE SEGMENT CONFIGURATION (OCT 1993)

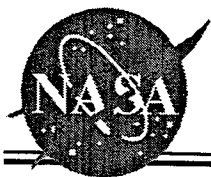


Office of Space Communications

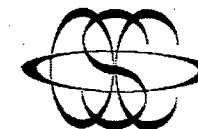


F1 PROVIDES LOW DATA RATE TO GRO VIA MA OR SA AND COMSAT RELAY,  
F3 HAS REDUCED CAPABILITY

OX/SND-266A  
10/17/93



# SPACE NETWORK OPERATIONAL STATUS



Office of Space Communications

	F1 APR 83	F3 SEP 88	F4 MAR 89	F5 AUG 91	F6 JAN 93
<b>USER SERVICE</b>					
<b>FORWARD</b>					
	SA-E	SA-E	SA-E	SA-E	SA-E
	SA-W	SA-W	SA-W	SA-W	SA-W
K-BAND	●	○	○	○	○
S-BAND	●	○	○	○	○
MA	○	○	○	○	○
<b>RETURN</b>					
K-BAND	○	○	○	○	○
S-BAND	●	○	○	○	○
MA	○	○	○	○	○
<b>SPACECRAFT</b>					
	○	○	○	○	○
K-BAND SGL	○	○	○	○	○
SYSTEMS	⦶	○	⦶	○	○

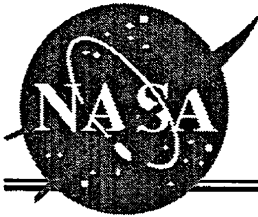
○ FULL

⦶ CONDITIONAL  
(OPERATING W/O REDUNDANCY-PRIMARY FAILED)

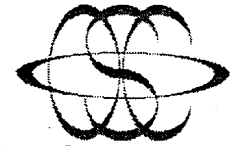
● FAILED

ONLY TDRS-5 AND TDRS-6 ARE WITHOUT FAILURES

OX/SND-270b  
4/6/93



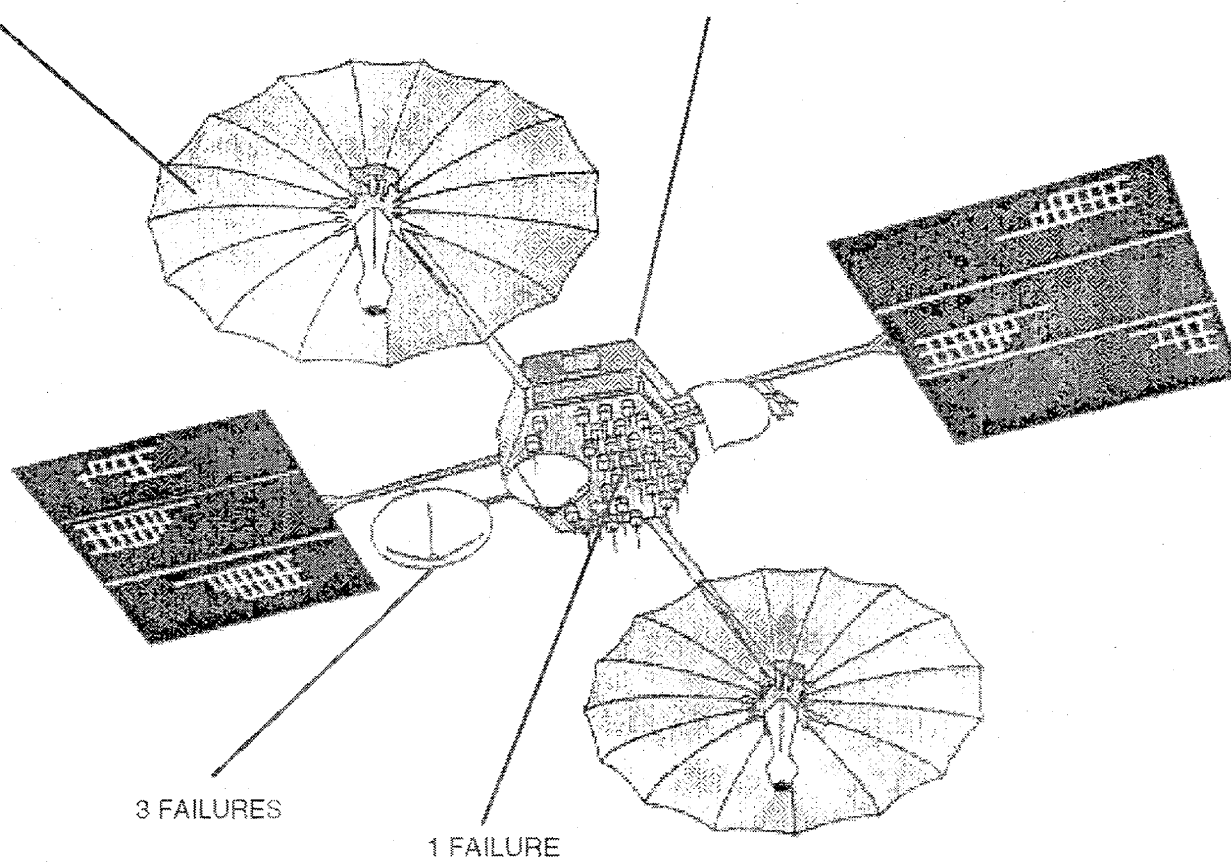
# SPACE NETWORK FAILURE LOCATIONS



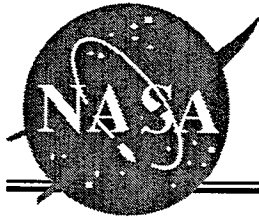
Office of Space Communications

14 FAILURES

1 FAILURE

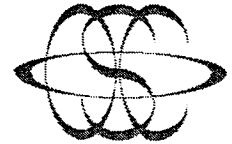






# What Can SELVs Do For Us?

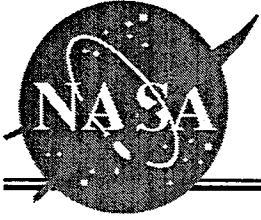
## *CURRENT GENERATION*



Office of Space Communications

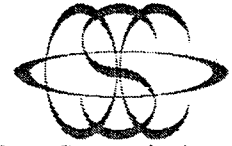
### **CURRENT DESIGN NOT CONDUCTIVE**

- REPAIR
  - POTENTIALLY COMPLEX DISASSEMBLY
  - SOLDERING/DESOLDERING
  - NOT MODULARIZED FOR REMOVAL REPLACEMENT
- RETRIEVAL & REBOOST ("SPACE TUG")
  - 2+ TON SPACECRAFT
  - DELICATE NON-RESTOWABLE APPENDAGES
- FUEL REPLENISHMENT
  - SEALED FUEL TANKS
  - EMBEDDED IN SPACECRAFT BODY
  - GENEROUS SUPPLY
- BATTERY REPLACEMENT
  - PERMANENTLY INSTALLED IN SPACECRAFT BODY
  - NO HISTORY OF BATTERY DEPLETION
- REPLACE SOLAR ARRAYS
  - REPLACE WHOLE ARRAY
  - NO HISTORY OF FAILURES
- DEBRIS MANAGEMENT



# What Can SELVs Do For Us?

## *FUTURE GENERATIONS*



Office of Space Communications

### **FUTURE DESIGNS CAN BE CONDUCTIVE**

- THREE "FUNCTIONALLY EQUIVALENT" TDRS FUNDED
  - RELATIVELY SHORT LEAD TIME
  - ALMOST CERTAIN TO BUY MORE
- FUTURE DESIGNS DEPEND ON RELATIVE COSTS
  - RELIABILITY VERSUS MAINTAINABILITY
  - REPAIR VERSUS REPLACEMENT
- BOTTOM LINE: ANYTHING IS POSSIBLE!

**NASA/INTEC**

**90-DAY SATELLITE SALVAGE STUDY**

**NOVEMBER 2, 1992**

## **AGENDA**

- **OBJECTIVES**
- **APPROACH**
- **FORECAST**
- **IMPLICATIONS FOR A REPAIR BUSINESS**
- **CONCLUSIONS**

## STUDY PARTICIPANTS

### NASA

- GEORGE LEVIN, NASA HQ, CODE DDS
- GREG DAVIDSON, NASA HQ, CODE SZ
- ED FALKENHAYN, GSFC, CODE 442
- RUTHAN LEWIS, NASA HQ, CODE DDS

### INTEC

- RICK HAUCK, PRESIDENT AND CEO
- PETER STARK, CONSULTANT
- PAT RIVALAN, SENIOR VICE PRESIDENT
- LYNNE VOLLMER, GENERAL COUNSEL

### KPMG PEAT MARWICK

- FRANK DIBELLO, PARTNER
- BILL SCHICK, SENIOR MANAGER

### DEPARTMENT OF DEFENSE

- MAJOR GARY SEIGAL, OFFICE OF SECRETARY OF THE AIR FORCE

### AEROSPACE CORPORATION

- LARRY ULMER

## **APPROACH**

- **REVIEW PREVIOUS CIVIL, DEFENSE, AND COMMERCIAL SPACECRAFT FAILURES**
- **FORECAST NUMBER AND ESTIMATED VALUE OF FUTURE CIVIL, DEFENSE, AND COMMERCIAL SPACECRAFT**
- **CALCULATE THE PRICE AT WHICH REPAIR BECOMES ATTRACTIVE (COMPARED TO REPLACEMENT)**
- **FORECAST THE NUMBER OF REPAIR OPPORTUNITIES BY EXTRAPOLATION FROM HISTORICAL FAILURE RATES**
- **EXAMINE THE FORECAST OF REPAIR OPPORTUNITIES FROM THE PERSPECTIVE OF A POTENTIAL COMMERCIAL SALVAGE VEHICLE OPERATOR**

## HISTORICAL FAILURE STATISTICS

- FROM 1980 TO DATE, THERE WERE 328 FREE-FLYING SPACECRAFT LAUNCHED
- THOSE 328 SPACECRAFT WERE LAUNCHED ALONG THE FOLLOWING INCLINATIONS:

- 28.5 DEGREES OR CLOSE THERETO ("CAPE")	154
- INCLINATIONS WELL ABOVE 28.5 TO POLAR ("HIGH")	106
- LESS THAN 10 DEGREES ("KOUROU")	68

- OF THE 328 LAUNCHES, 64 SPACECRAFT EXPERIENCED SOME TYPE OF TOTAL OR SIGNIFICANT PARTIAL FAILURE, OCCURRING DURING THE FOLLOWING PHASES OF FLIGHT:

		TOTAL/PARTIAL
ASCENT TO LOW EARTH ORBIT (LEO)(SPACECRAFT DESTROYED)	21	(21/0)
PROPULSIVE FAILURE - LEO TO HIGHER ORBIT	13	(10/3)
SPACECRAFT FAILURE - DURING CHECKOUT	19	(5/14)
ON-ORBIT OPERATIONS FAILURE (POST-CHECKOUT)	11	(7/4)

## ILLUSTRATION OF FINANCIAL MODEL

- A FINANCIAL MODEL WAS DESIGNED TO COMPARE THREE BASIC SCENARIOS – REPAIR, REPLACE, AND DO NOTHING
  - REPLACE SCENARIO SPREADS THE COST OF REPLACEMENT EVENLY OVER "REPLACE TIME", THEN COLLECTS REVENUES FOR THE FULL LIFE OF THE SPACECRAFT
  - REPAIR SCENARIO SPREADS COST OF REPAIR OVER "REPAIR TIME," THEN COLLECTS REVENUES FOR THE REMAINDER OF SPACECRAFT LIFE LESS "REPAIR TIME"
  - DO NOTHING SCENARIO IMPLIES COLLECTING INSURANCE (WHERE APPLICABLE) AND NOT REPLACING THE SPACECRAFT
- REPAIR SCENARIO FOR INSURED SPACECRAFT:
  - COLLECTS AN INSURANCE CLAIM IN THE FIRST YEAR
  - REQUIRES SHARING REVENUES WITH INSURERS UP TO AMOUNT OF INSURANCE CLAIM RECEIVED



## ILLUSTRATION OF FINANCIAL MODEL (CONT.)

- PARAMETERS FOR ILLUSTRATION:

- |   |   |
|---|---|
| <ul style="list-style-type: none"> <li>- REPLACEMENT COST: \$150M OVER 3 YEARS</li> <li>- REVENUES (NET): \$100M PER YEAR</li> <li>- LIFE: 10 YEARS</li> <li>- DISCOUNT RATE: 7 PERCENT</li> <li>- REPAIR TIME: 1 YEAR</li> </ul> | <ul style="list-style-type: none"> <li>- REPLACEMENT SUCCESS RATE: 85%</li> <li>- REPAIR SUCCESS RATE: 80%</li> </ul> |
|---|---|

### REPLACE SCENARIO:

YEAR	1	2	3	4	5	6	7	8	9	10	11	12	13	NET PRESENT VALUE (NPV)
COST	-50	-50	-50											
REVENUE				85	85	85	85	85	85	85	85	85	85	
CASH FLOW	-50	-50	-50	85	85	85	85	85	85	85	85	85	85	356M

- THE OBJECTIVE IS TO DETERMINE THE COST OF REPAIR AT WHICH THE REPAIR SCENARIO WILL BE AS ATTRACTIVE FINANCIALLY AS THE REPLACE SCENARIO (I.E., NET PRESENT VALUES ARE EQUAL)
- THE COST OF REPAIR IS THE UNKNOWN TO BE SOLVED FOR, WHICH IS DONE BY SETTING THE NPV FOR REPAIR TO \$356M, THE NPV FOR REPLACEMENT

### REPAIR SCENARIO:

COST	-TBD													
REVENUE		80	80	80	80	80	80	80	80	80				
CASH FLOW	-TBD	80	80	80	80	80	80	80	80	80				356M

- THE RESULTING REPAIR COST IS \$140M - THE "BREAKEVEN REPAIR COST"

# 1993-1996 LAUNCH MANIFEST

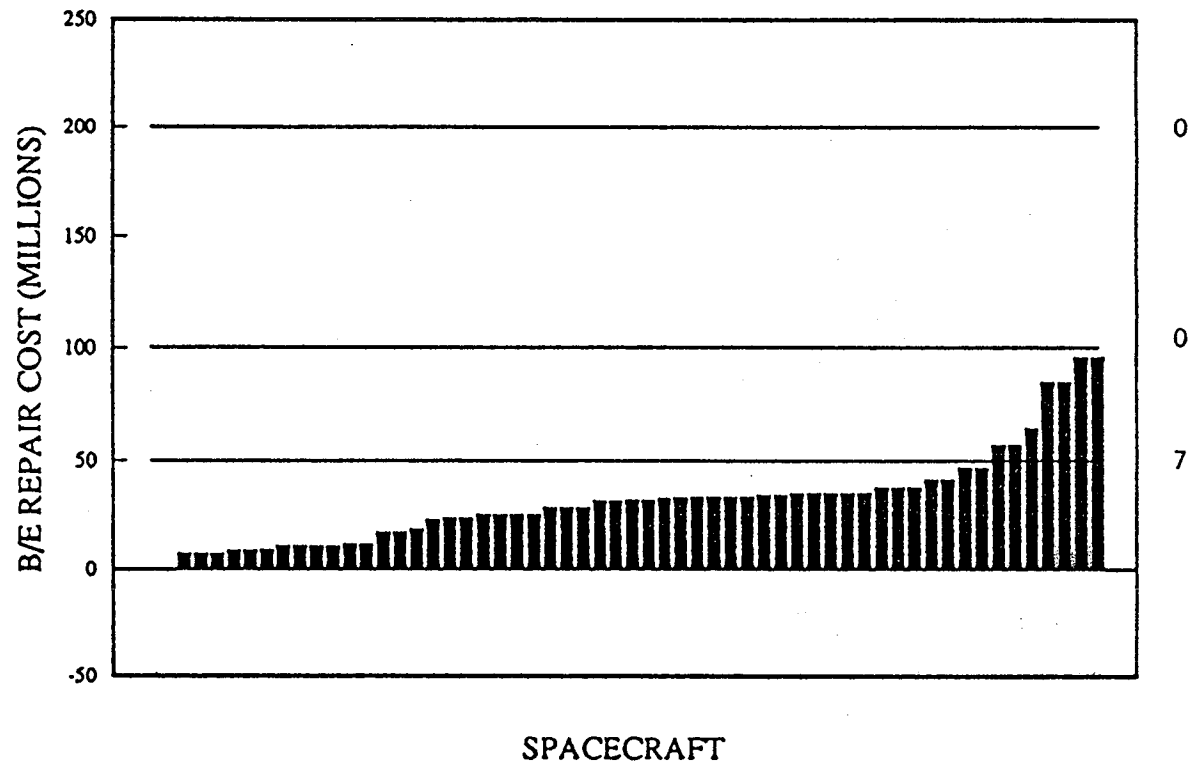
	1991 ACTUAL			1992 ACTUAL/EST.			1993			1994			1995			1996			TYPICAL YEAR			TOT
INCLIN	COM	CIV	DEF	COM	CIV	DEF	COM	CIV	DEF	COM	CIV	DEF	COM	CIV	DEF	COM	CIV	DEF	COM	CIV	DEF	93-96
CAPE	6	3	3	9	6	3	2	5	9	12	6	8	7	5	8	2	3	8	5	4	7	75
HIGH		4	3		3	5	1	3	11	1	1	8		1	5		2	11		3	7	44
KOUROU	9			12			7	1		19	1		6	1		1	1		10			37
	15	7	6	21	9	8	10	9	20	32	8	16	13	7	13	3	6	19	15	7	14	
TOTAL	28			38			39			56			33			28			36			156

## NOTES REGARDING THE MANIFEST:

- AS WITH THE HISTORICAL FIGURES, ONLY SALVAGE CANDIDATES ARE SHOWN (NO SHUTTLE-CAPTIVE MISSIONS)
- THE SOMEWHAT LARGE NUMBER OF LAUNCHES SHOWN IN 1994 REPRESENTS AN ESTIMATE AS OF LATE-1992, AND A NUMBER OF THESE LAUNCHES WILL PROBABLY SLIP INTO 1995 AND 1996
- THE "TYPICAL YEAR" IS AN INTEC JUDGEMENT BASED ON THE 1993-96 MANIFEST AND PAST EXPERIENCE

## THE FORECAST

- THE FINANCIAL MODEL PRODUCES THE FOLLOWING GRAPH OF BREAKEVEN REPAIR COSTS FOR THE 58 SPACECRAFT IN THE COMMERCIAL SEGMENT OF THE MARKET FOR 1993-1996



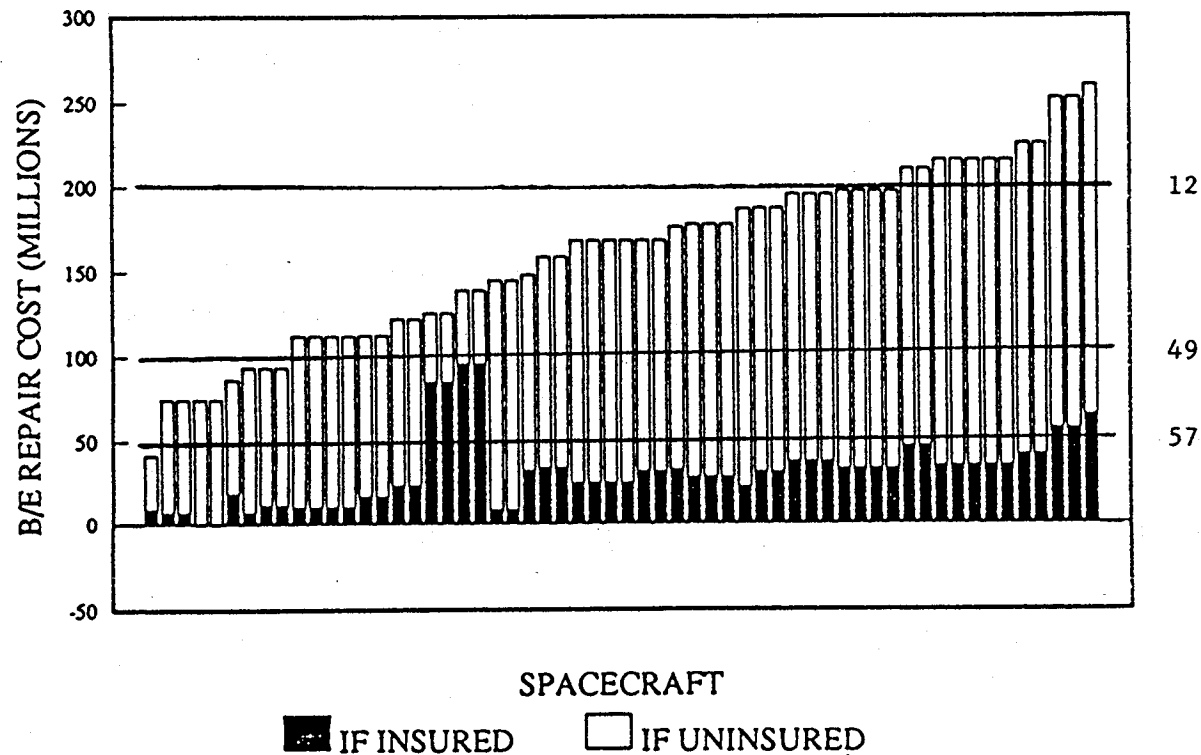
### COMMERCIAL MARKET 1993-96

- IN GENERAL, THE DISTRIBUTION OF VALUES IN THIS 4-YEAR EXAMPLE SHOULD BE REPRESENTATIVE OF THE SPREAD OF VALUES WHICH MIGHT OCCUR IN ANY SPECIFIC YEAR, SINCE THE MARKET CONDITIONS WHICH PRODUCE SUCH A DISTRIBUTION ARE INDEPENDENT OF WHEN THE SPACECRAFT ARE LAUNCHED



## THE FORECAST (CONT.)

- IF THE COMMERCIAL SPACECRAFT OWNERS DO NOT HAVE INSURANCE, OR DO NOT HAVE AN OBLIGATION TO REPAY SIGNIFICANT AMOUNTS TO INSURERS IF THEY COLLECT ON THEIR INSURANCE FOR THE FAILURE, THE BREAK-EVEN REPAIR COSTS ARE MUCH HIGHER



COMMERCIAL MARKET  
1993-96 - 58 S/C

## THE FORECAST (CONT.)

- A MECHANISM FOR GENERATING "QUASI-REVENUE" FIGURES FOR NON-COMMERCIAL SPACECRAFT WAS DEVELOPED
  - SET THE NET PRESENT VALUE OF ANNUAL "REVENUES" FOR CIVIL/DEFENSE SPACECRAFT (IN A NON-FAILURE MODE, I.E., YEARS 1 THRU "LIFE") AS EQUAL TO THE TOTAL ORIGINAL COST

EXAMPLE: A \$1B SPACECRAFT WITH A 5-YEAR LIFE WOULD RECEIVE REVENUES OF \$X AT THE END OF EACH OF THE FIVE YEARS. USING A 7 PERCENT DISCOUNT RATE, THE VALUE OF \$X SUCH THAT THE NET PRESENT VALUE OF FIVE SUCH PAYMENTS = \$1B IS \$244M

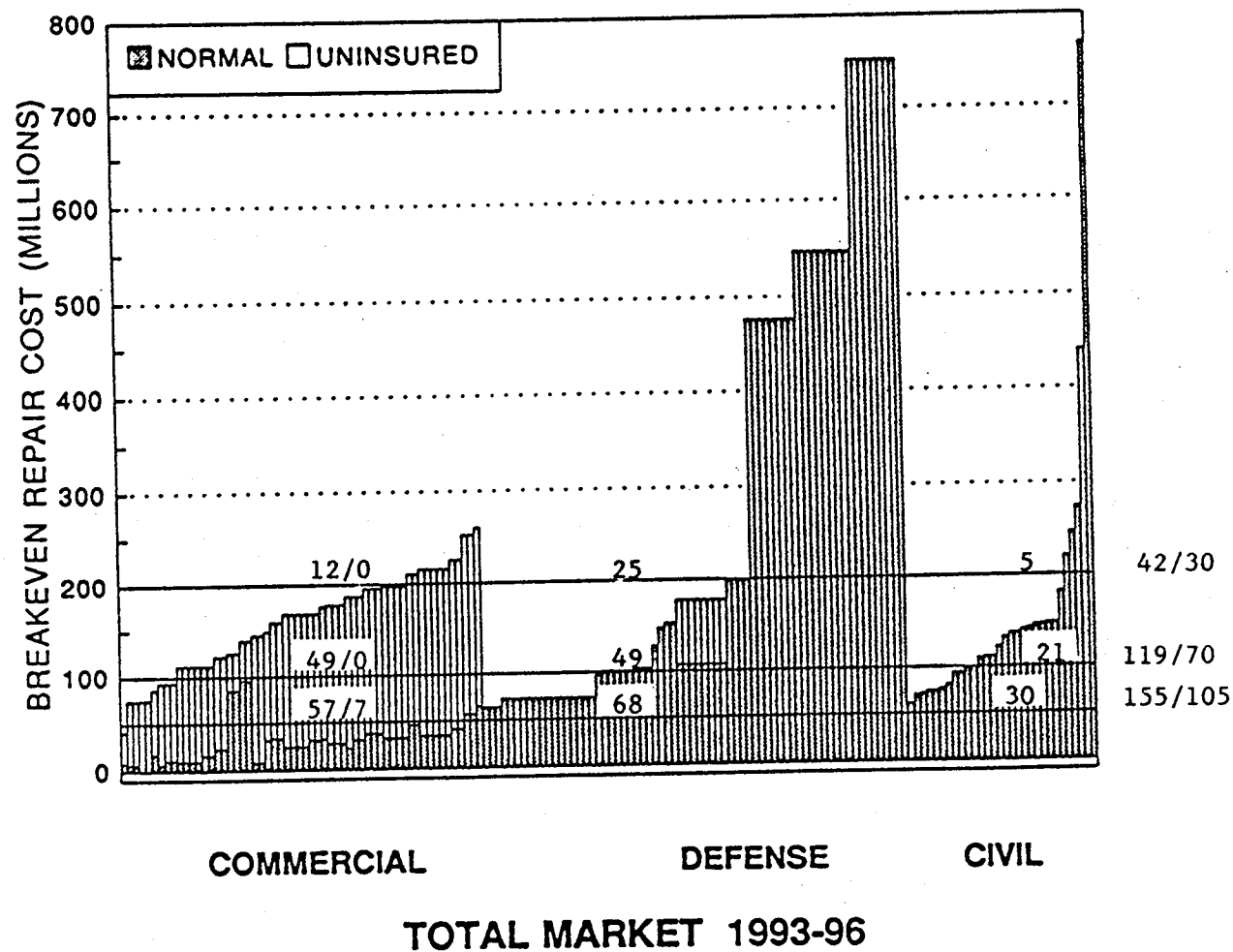
CAVEAT: THIS METHOD IS PRIMARILY USEFUL FOR ASSESSING A LARGE NUMBER OF SPACECRAFT IN THE AGGREGATE, AND SHOULD NOT BE APPLIED TO INDIVIDUAL SPACECRAFT EXCEPT AS PART OF A COMPLETE ANALYSIS WHICH INCLUDES ALL MAJOR UNQUANTIFIABLE ISSUES AS WELL

- OTHER FACTORS:

- FOR CIVIL GOVERNMENT SPACECRAFT, LOSS OF SCIENTIFIC OR REMOTE SENSING DATA, UNCERTAIN STATUS OF FUNDING FOR A REPLACEMENT SPACECRAFT
- FOR DEFENSE SPACECRAFT, LOSS OF CURRENT RECONNAISSANCE OR COMMUNICATIONS CAPABILITY

## THE FORECAST (CONT.)

• COMBINING THE RESULTS FOR THE THREE MARKET SEGMENTS ON A COMMON SCALE PRODUCES THE FOLLOWING GRAPH OF BREAKEVEN REPAIR COSTS FOR THE 156 SPACECRAFT IN THE TOTAL MARKET FOR 1993-1996



## FORECAST OF TOTAL FAILURES

	HISTORICAL FAILURES BY SEGMENT (328)			FAILURE RATE BY SEGMENT			POTENTIAL FAILURES IN A TYPICAL YEAR*		
	COM	CIV	DEF	COM	CIV	DEF	COM	CIV	DEF
LAUNCH	9	5	7	6.3%	6.6%	6.4%	.945	.462	.896
BOOST	5	2	3	3.5%	2.6%	2.7%	.525	.182	.378
INIT OPS	4	0	1	2.8%	0.0%	0.9%	.420	.000	.126
ON-ORB	2	5	0	1.4%	6.6%	0.0%	.210	.462	.000
SUBTOTAL	20	12	11	14.1%	15.8%	10.0%	2.12	1.11	1.40
CANDIDATES	11	7	4	7.7%	9.2%	3.6%	1.16	0.64	0.50

\* THIS FORECAST MARKET INCLUDES ALL INCLINATIONS, ALTITUDES, AND FAILURE MODES



## IMPLICATIONS OF THE FORECAST FOR A REPAIR BUSINESS

- THE QUESTION FOR A POTENTIAL REPAIR BUSINESS IS WHETHER IT CAN OFFER A REPAIR SERVICE AT A PRICE WHICH IS SUFFICIENTLY LOW TO CAPTURE ENOUGH FAILURES TO REPRESENT A MARKET FOR ITS SERVICE

### CAVEAT #1:

- EACH REPAIR MISSION WILL BE UNIQUE
  - THE COMPLETE SET OF SALVAGEABLE MISSIONS INCLUDES ALL INCLINATIONS AND ECCENTRICITIES, I.E., LEO, POLAR, GEOSYNCHRONOUS TRANSFER ORBIT, GEOSTATIONARY ORBIT, AND A FEW ELLIPTICAL ORBITS
  - HISTORICALLY, WHILE THE MOST COMMON SALVAGEABLE FAILURE WAS AN UPPER STAGE FAILURE (THUS REQUIRING ONLY A NEW BOOSTER STAGE), OTHERS INVOLVED:
    - .. DEPLOYMENT FAILURES (E.G., TVSAT-1)
    - .. COMMUNICATIONS FAILURES (SYNCOM IV F4)
    - .. MOMENTUM WHEEL FAILURES (SOLAR MAX)
    - .. TRANSPONDER FAILURES (BS 2A)
    - .. ATTITUDE CONTROL FAILURES (TELECOM I B, SUPERBIRD A)
- THE TYPE OF SALVAGE CAPABILITY TO ADDRESS THIS SPECTRUM OF POTENTIAL FAILURES IS QUITE COMPLEX, AND THE FULL MARKET OF POTENTIAL FAILURES IS ONLY AVAILABLE TO SOMEONE WHO CAN FIX ALL OF THEM (AN EXPENSIVE PROPOSITION)
- ANY OF THESE WHICH A SALVAGE OPERATOR CANNOT HANDLE REDUCES HIS POTENTIAL MARKET

## IMPLICATIONS OF THE FORECAST FOR A REPAIR BUSINESS (CONT.)

### CAVEAT #2A:

- THE MODEL MAY BE OPTIMISTIC IN ASSUMING A 20 PERCENT FAILURE RATE FOR SALVAGE MISSIONS (VERSUS 15 PERCENT FOR REPLACEMENT MISSIONS)

### CAVEAT #2B:

- WHILE REPAIR IS ALMOST CERTAINLY RISKIER THAN REPLACEMENT, AND THE DIFFERENCE MAY BE MORE THAN 5 PERCENT, SINCE THERE ARE A NUMBER OF NON-FINANCIAL FACTORS WHICH FAVOR REPAIR AND WOULD HELP TO OFFSET A HIGHER REPAIR MISSION RISK, THE 5 POINT DIFFERENTIAL WAS USED
- THE NON-FINANCIAL ADVANTAGES OF REPAIR MISSIONS MAY INCLUDE:
  - FOR COMMERCIAL SPACECRAFT, FIRST-TO-MARKET AND MARKET SHARE CONSIDERATIONS
  - FOR CIVIL GOVERNMENT SPACECRAFT, LOSS OF SCIENTIFIC OR REMOTE SENSING DATA, COMBINED WITH DIFFICULTY AND LONG LEAD TIME ASSOCIATED WITH FUNDING A REPLACEMENT SPACECRAFT
  - FOR DEFENSE SPACECRAFT, LOSS OF CURRENT RECONNAISSANCE OR COMMUNICATIONS CAPABILITY

## **CONCLUSIONS**

- **THE NUMBER AND VALUE OF SPACECRAFT WHICH MAY REQUIRE REPAIR MAY NOT BE SUFFICIENT TO SUPPORT A STANDALONE SALVAGE OPERATION, BUT MIGHT REPRESENT A VIABLE SECONDARY MARKET IF THE SALVAGE OPERATOR HAS A BASELINE SPACECRAFT SERVICING BUSINESS**
- **THE U.S. GOVERNMENT REPRESENTS A SIZEABLE PORTION OF THE POTENTIAL MARKET FOR SALVAGE, AND FOR A COMMERCIAL SALVAGE OPERATOR TO SUCCEED, THE U.S. GOVERNMENT WOULD PROBABLY HAVE TO BE A CUSTOMER FOR ITS SERVICES**

## **ASSUMPTIONS**

**THE FOLLOWING ASSUMPTIONS ARE USED IN THE FINANCIAL MODEL OF FUTURE LAUNCHES:**

- **ALL THE FORECAST MISSIONS WILL OCCUR, OR EQUIVALENTLY, APPROXIMATELY THAT NUMBER AND DISTRIBUTION WILL OCCUR DURING ROUGHLY THE SAME PERIOD**
- **FUTURE LAUNCHES WILL EXPERIENCE A SIMILAR DISTRIBUTION OF FAILURES AS THOSE IN THE 12+ YEARS SURVEYED**
- **ALL AMOUNTS ARE IN CONSTANT 1992 DOLLARS**
- **"REPLACEMENT COST" IS EQUAL TO ORIGINAL COST**
- **THE "INSURED FOR" AMOUNT IS EQUAL TO THE REPLACEMENT COST WHEREVER INSURANCE IS USED**
- **"REPLACEMENT TIME" IS 3 YEARS, EXCEPT 7 YEARS FOR UNIQUE GOVERNMENT SPACECRAFT (E.G. SCIENTIFIC)**
- **REPAIRS REQUIRING MORE THAN 1 YEAR ARE PROBABLY TOO DIFFICULT AND THUS ALSO TOO EXPENSIVE TO BE INCLUDED IN THE SAME CLASS AS THE GENERIC "BREAKEVEN REPAIR COST" BEING CALCULATED**
- **THE BREAKEVEN REPAIR COST INCLUDES INSURANCE AT A PREMIUM OF ROUGHLY 20-25 PERCENT**
- **REPAIR AND REPLACEMENT LAUNCHES ARE ASSUMED TO HAVE FAILURE RATES OF 20 AND 15 PERCENT, RESPECTIVELY; TO COMPENSATE FOR THIS, BOTH REVENUE STREAMS ARE REDUCED BY THE APPROPRIATE PERCENTAGE TO REPRESENT THE AGGREGATE EFFECT ON EXPECTED VALUES**

## **ASSUMPTIONS (CONT.)**

- **MANEUVERS REQUIRED FOR THE REPAIR SCENARIO REDUCE LIFE BY THE AMOUNT OF THE REPAIR TIME**
- **"REMAINING LIFE" EQUALS DESIGN LIFE (LESS REPAIR TIME IN REPAIR SCENARIO)**
- **ANNUAL "REVENUES" FOR COMMERCIAL SPACECRAFT ARE ESTIMATED BASED ON THE CLASS OF SPACECRAFT USING HISTORICAL INSURANCE AMOUNTS AND/OR INDUSTRY KNOWLEDGE; AS A FIRST CUT, REVENUES ARE ASSUMED TO EQUAL PROFIT (LACKING A GOOD ESTIMATE OF COSTS FOR COMMERCIAL)**
- **"REPAIR SHARE" (PORTION OF REVENUES REPAID TO INSURERS IN EXCHANGE FOR RECEIVING INSURANCE CLAIM IN YEAR 1) IS EQUAL TO HALF OF FUTURE REVENUES LIMITED BY THE AMOUNT OF INSURANCE PAID**
- **THE "DISCOUNT RATE" FOR CALCULATING NET PRESENT VALUE IS 7 PERCENT**
- **THE HISTORICAL FAILURE STATISTICS INCLUDE ONLY TOTAL FAILURES, ON THE ASSUMPTION THAT PARTIAL FAILURES WOULD PROBABLY NOT WARRANT MOUNTING A REPAIR MISSION**
- **ONLY SPACECRAFT WHICH WERE PRIMARY PAYLOADS ON LARGE LAUNCH VEHICLES WERE CONSIDERED CANDIDATES FOR SALVAGE (ASSUMES SMALL SPACECRAFT ARE INEXPENSIVE TO REPLACE)**
- **HISTORICAL AND FUTURE SPACECRAFT INCLUDED IN THE ANALYSIS INCLUDE ALL KNOWN SPACECRAFT ABOVE THE SIZE LIMIT, INCLUDING CHINESE AND JAPANESE, BUT EXCLUDING SOVIET/CIS**
- **WHERE SPECIFIC DATA WAS NOT AVAILABLE FOR CERTAIN SPACECRAFT, ESTIMATES WERE USED WHICH WERE CONSISTENT WITH OTHER COMPARABLE SPACECRAFT IN THE DATA BASE**

MEMORANDUM OF UNDERSTANDING BETWEEN INTERNATIONAL  
TECHNOLOGY UNDERWRITERS, INC. (INTEC) AND THE  
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION (NASA)

The purpose of this Memorandum of Understanding (MOU) is to provide a basis for an exchange of information to facilitate INTEC's examination of commercial approaches to rescue and repair missions.

WHEREAS:

- NASA and commercial satellite owners and insurers have, in the past, cooperated in salvaging, retrieving, or repairing various spacecraft;
- NASA and INTEC believe that occasions will arise in the future where the ability to salvage satellites would be greatly beneficial;
- Substantial expense and some risks are associated with the execution of human space shuttle salvage missions;
- INTEC is interested in assisting in the study of a robotic satellite rescue and repair capability;
- NASA is fully supportive of efforts to investigate and develop alternative methods of satellite rescue and repair which do not require the space shuttle and human intervention;
- NASA and INTEC are committed to encouraging further development of commercial space activity; and
- NASA recognizes that INTEC's core business is to provide insurance for commercial space ventures and other high technology endeavors.

NOW THEREFORE:

NASA and INTEC affirm the following propositions for coordinating their activities:

- INTEC, on a nonexclusive basis, will assist NASA in identifying the commercial risk allocation implications of satellite rescue and repair missions and in developing standard contract provisions for use in future NASA missions;
- NASA will provide to INTEC historical data, on a nonexclusive basis, regarding civil spacecraft which have suffered partial or total failures and which would have been candidates for salvage;

- INTEC will attempt to determine how many failed commercial spacecraft might have been salvaged;
- INTEC will explore creative methods in which the insurance industry may assist in financing human or robotically conducted salvage missions and in encouraging or incentivizing owners of commercial spacecraft to buy satellites incorporating salvage-friendly features;
- The points of contact for effort under this MOU shall be:

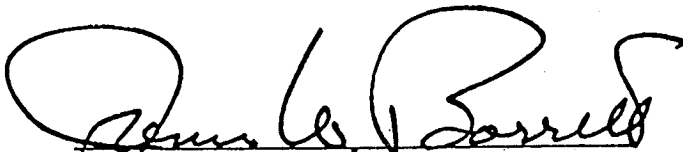
Frederick H. Hauck  
President  
International Technology  
Underwriters, Inc.  
4800 Montgomery Lane  
Bethesda, MD 20814  
(301) 654-8585


Arnold D. Aldrich  
Associate Administrator  
for Space Systems Development  
National Aeronautics and  
Space Administration  
Washington, D.C. 20546  
(202) 453-1161

- INTEC will present its initial findings and recommendations to NASA within 90 days of the date this MOU is signed.

INTEC is neither an agent, representative, or contractor of NASA, nor is it an official part of the United States space program.

This MOU may be terminated at any time by either party upon written notice.

  
James W. Barrett  
Chairman and CEO  
International Technology  
Underwriters, Inc.  
(INTEC)

  
Daniel S. Goldin  
Administrator  
National Aeronautics and Space  
Administration  
(NASA)

Date: June 30, 1992

Date: June 30, 1992

## SENSITIVITY ANALYSIS

A SENSITIVITY ANALYSIS WAS CONDUCTED TO DETERMINE HOW THE BREAKEVEN (B/E) REPAIR COST WOULD BE AFFECTED BY CHANGES IN THE VARIOUS INPUT VARIABLES

***NOTE: WHEN BREAKEVEN REPAIR COSTS GO DOWN, REPAIR BECOMES LESS ATTRACTIVE***

- **REPAIR TIME:** B/E REPAIR COSTS DROP RAPIDLY WHEN REPAIR TIME IS INCREASED  
**RATIONALE:** THE EARLY RESUMPTION OF REVENUES IS A CRITICAL PART OF THE ADVANTAGE TO REPAIRING, HENCE THE LATER THE REPAIR, THE LESS ADVANTAGE
- **REPLACE TIME:** B/E REPAIR COSTS RISE SUBSTANTIALY AS REPLACEMENT TIME INCREASES  
**RATIONALE:** THE LONGER IT TAKES TO REPLACE, THE BETTER THE EARLY REVENUES FROM REPAIR APPEAR
- **LIFE:** B/E REPAIR COSTS RISE GRADUALLY WITH LONGER SPACECRAFT LIVES  
**RATIONALE:** AN ADDITIONAL YEAR OF REVENUE IS WORTH MORE IN THE REPAIR SCENARIO BECAUSE IT OCCURS EARLIER, MAKING REPAIR MORE AFFORDABLE
- **REVENUE:** B/E REPAIR COSTS FALL VERY SLOWLY WITH INCREASING ANNUAL REVENUE  
**RATIONALE:** THE BENEFIT OF HIGHER REVENUES IS SLIGHTLY OVERCOME BY THE HIGHER RISK OF THE REPAIR SCENARIO



## SENSITIVITY ANALYSIS (CONT.)

- **COST, WITH INSURANCE:**      B/E REPAIR COSTS RISE VERY SLOWLY WITH HIGHER SPACECRAFT COST  
  
    **RATIONALE:**      COLLECTING AN INSURANCE CLAIM AMOUNTS TO TAKING OUT A LOAN WHICH MUST BE PAID BACK; REPAIRING A MORE EXPENSIVE SPACECRAFT MEANS HAVING LESS OF THE (FIXED) REVENUES AVAILABLE TO PAY FOR THE REPAIR
- **COST, WITHOUT INSURANCE:** B/E REPAIR COSTS RISE FAIRLY QUICKLY WITH HIGHER SPACECRAFT COSTS  
  
    **RATIONALE:**      THE HIGHER THE SPACECRAFT COST, THE MORE EXPENSIVE THE REPLACEMENT MISSION, HENCE A REPAIR CAN COST MORE
- **UNDER-INSURING:**      B/E REPAIR COSTS RISE QUICKLY AS THE DEGREE OF FULL-INSURANCE IS REDUCED BELOW 100 PERCENT  
  
    **RATIONALE:**      SINCE INSURANCE IMPLIES LESS REVENUES IN THE REPAIR SCENARIO, LESS INSURANCE MEANS MORE REVENUES, MAKING A MORE EXPENSIVE REPAIR AFFORDABLE
- **INSURER'S REVENUE SHARE:**      B/E REPAIR COSTS RISE SLOWLY AS THE PERCENTAGE OF REVENUES USED TO REPAY INSURERS IS REDUCED (HOWEVER, BELOW ABOUT 25 PERCENT, B/E REPAIR COSTS RISE VERY RAPIDLY, AS YOU APPROXIMATE THE "UNINSURED" SITUATION)  
  
    **RATIONALE:**      SLOWER REPAYMENT TO INSURERS MEANS MORE EARLY REVENUES AVAILABLE TO PAY FOR A REPAIR

## SENSITIVITY ANALYSIS (CONT.)

- **DISCOUNT RATE:** B/E REPAIR COSTS RISE GRADUALLY WITH INCREASING DISCOUNT RATE

**RATIONALE:** THE OUT-YEAR REVENUES IN THE REPLACE SCENARIO ARE LESS VALUABLE WITH HIGHER DISCOUNT RATE, HENCE MORE EXPENSIVE REPAIRS ARE AFFORDABLE

- **FAILURE RATE:** B/E REPAIR COSTS FALL VERY SLOWLY WITH INCREASING RATES OF FAILURE FOR BOTH REPAIR AND REPLACEMENT MISSIONS (IF EQUAL RATES FOR EACH)

**RATIONALE:** EFFECT IS TO LOWER REVENUES, HENCE CAN AFFORD LESS EXPENSIVE REPAIRS

86

- **DIFFERENTIAL FAILURE RATES:** INCREASING THE FAILURE RATE OF THE REPAIR SCENARIO ABOVE THAT FOR REPLACE REDUCES B/E REPAIR COST FAIRLY RAPIDLY (THE FAILURE RATES ARE USED TO REDUCE ONLY REVENUES, NOT COSTS)

**RATIONALE:** REDUCING REVENUES IN THE REPAIR SCENARIO QUICKLY REDUCES THE ABILITY OF THE "EARLY" REVENUES OFFERED BY REPAIR TO OFFSET THE ADDITIONAL YEARS AVAILABLE THROUGH REPLACE

AN ALTERNATIVE MEANS OF ACCOUNTING FOR THE HIGHER RISK OF THE REPAIR SCENARIO (AS OPPOSED TO USING A HIGHER FAILURE RATE APPLIED TO REVENUES, ABOVE) IS TO USE A HIGHER DISCOUNT RATE FOR ALL THE CASH FLOWS (COSTS AS WELL AS REVENUES):

- **DIFFERENTIAL DISCOUNT RATES:** INCREASING THE DISCOUNT RATE FOR THE REPAIR SCENARIO ABOVE THAT FOR REPLACE REDUCES THE B/E REPAIR COST FAIRLY RAPIDLY

**RATIONALE:** SINCE REPAIR TAKES ONLY ONE YEAR, THE LARGEST AFFECT OF HIGHER DISCOUNT RATE IS ON REVENUES, AND LOWER REVENUES MEAN LESS AFFORDABLE REPAIRS

## EFFECTS OF INSURANCE

- THE PRESENCE OR ABSENCE OF INSURANCE HAS A MAJOR EFFECT ON THE BREAK-EVEN REPAIR COST
  - B/E REPAIR COSTS ARE LOWER BY 80-90% OF THE COST OF THE SPACECRAFT WHEN THE SPACECRAFT IS INSURED; E.G., IN THE ILLUSTRATION ON PAGE 6, IF THE SPACECRAFT WAS FULLY INSURED FOR ITS \$150M COST, THE B/E REPAIR COST WOULD BE \$12M INSTEAD OF \$140M
- THIS EFFECT MAKES A SUBSTANTIAL DIFFERENCE IN THE ATTRACTIVENESS OF THE COMMERCIAL MARKET TO A POTENTIAL SALVAGE OPERATOR
- WHILE THE "IF INSURED" BREAK-EVEN REPAIR COSTS WERE CALCULATED FROM THE PERSPECTIVE OF A SPACECRAFT OWNER CONSIDERING SALVAGE, THE "IF UNINSURED" VALUES REPRESENT THE PERSPECTIVE OF THE INSURERS (WHO ARE THEMSELVES UNINSURED)
  - INSURERS ONLY HAVE ACCESS TO REVENUES VIA THE OWNER
  - INSURERS COULD CONCEIVABLY TAKE POSSESSION OF THE SPACECRAFT AND SELL IT AFTER REPAIR, BUT DON'T NORMALLY HAVE THE RIGHT TO DO SO (SINCE PALAPA/WESTAR)
  - OWNER COULD CHOOSE NOT TO COLLECT ON INSURANCE, THUS AFFORDING MORE EXPENSIVE REPAIR, THEN COLLECT ONLY IF REPAIR FAILS
- IF THE OWNER/INSURER IS VIEWED AS A SINGLE UNIT WHICH COLLECTIVELY "OWNS" THE SPACECRAFT, THEN INSURANCE DISAPPEARS FROM THE PICTURE AND THE MARKET IS THE "UNINSURED" BREAK-EVEN REPAIR COSTS

## STIMULATING SALVAGE-FRIENDLINESS

**PROBLEM:** TO DATE, SPACECRAFT MANUFACTURERS AND OWNERS HAVE CHOSEN NOT TO INCORPORATE SALVAGE-FRIENDLY FEATURES, PREFERRING INSTEAD TO ALLOCATE AVAILABLE MASS AND FINANCIAL RESOURCES TO PROVISION OF HARDWARE WITH MORE DIRECT REVENUE PRODUCING POTENTIAL (E.G., COMMUNICATIONS CAPABILITIES) OR RELIABILITY ENHANCEMENT FEATURES (E.G., REDUNDANCY, GROUND TESTING)

### **ALTERNATIVES:**

- **INSURERS**
  - COULD OFFER REDUCED INSURANCE RATES, BUT BENEFIT IS SMALL AND AMOUNT OF REDUCTION MAY BE TOO SMALL TO REPRESENT MUCH OF AN INCENTIVE TO OWNERS (0.5 TO 1.0 PERCENT ON \$150M IS \$750-1500K, BUT ALSO COSTS LIFE; PERHAPS ON BLOCK BUYS?)
  - COULD ENCOURAGE OWNERS TO PROCURE SALVAGE-FRIENDLY SPACECRAFT THRU SALVAGE-RELATED POLICY FEATURES
  - COULD INVEST IN COMMERCIAL SALVAGE OPERATION BUSINESS
- **OWNERS**
  - COULD REQUIRE SALVAGE-FRIENDLY FEATURES IN PROCUREMENTS (MOST EFFECTIVE IN BLOCK BUYS)

**NOTE:** SALVAGE-FRIENDLY FEATURES ARE DIFFICULT TO DESIGN IN THE ABSENCE OF A DEFINITION OF WHAT THE PHYSICAL MEANS OF SALVAGE WOULD BE. FURTHER, THERE MUST BE A HIGH LEVEL OF CONFIDENCE THAT SUCH SALVAGE HARDWARE WILL BE AVAILABLE AND WILL WORK BEFORE THE SALVAGE-FRIENDLY FEATURES FIND THEIR WAY ONTO THE SPACECRAFT

## SUMMARY

- IN THE "TYPICAL" YEAR THERE IS A MARKET OF 1.6 FAILURES PER YEAR IN THE BOOST/INITIAL OPERATIONS PHASES AND .67 IN THE ON-ORBIT PHASE (TOTAL 2.3 FAILURES PER YEAR)
- THIS ASSUMES THE FORECAST NUMBER OF FAILURES OCCUR WITH "AVERAGE" FREQUENCY
- THE DISTRIBUTION OF VALUES FOR THE BREAKEVEN REPAIR COST (156 SPACECRAFT IN 1993-96) IS:

	COMMERCIAL (INSURED)	COMMERCIAL (UNINSURED)	CIVIL	DEFENSE (UNINSURED)	TOTAL (UNINSURED)
NO. OF S/C	58	58	30	68	156
LOW	0.0M	41.6M	60.7M	64.0M	41.6M
MEDIAN	31.6M	168.3M	122.0M	177.8M	152.5M
AVERAGE	31.4M	160.1M	158.6M	290.5M	216.6M
HIGH	95.7M	260.4M	768.4M	751.9M	768.4M

- FOR THIS TO REPRESENT A REAL MARKET FOR A SALVAGE OPERATOR:
  - ALL FAILURES MUST BE IN REACHABLE ORBITS AND HAVE FAILURES WHICH THE OPERATOR IS EQUIPPED TO SERVICE FOR LESS THAN THE BREAKEVEN REPAIR COST
  - ALL SPACECRAFT OWNERS MUST BE MOTIVATED TO CHOOSE REPAIR OVER REPLACEMENT

# TABLE OF SENSITIVITIES\*

SENSITIVITY TO:	CHANGE IN PARAMETER	CHANGE (\$M) IN B/E REPAIR COST	
COST - WITH INSURANCE	+10 %	2.8	↑
COST - WITHOUT INSURANCE	+10 %	14.0	↑
UNDER-INSURING	-10 %	11.4	↑
REPLACE TIME	+1 YEAR	29.6	↕
REPAIR TIME	+1 YEAR	-72.6	↕
LIFE	+10 %	5.4	↑
REVENUE - WITH INSURANCE	+10 %	-1.4	↓
REVENUE - WITHOUT INSURANCE	+10 %	-0.02	—
INSURER REPAYMENT SHARE	+10 %	-1.3	↓
DISCOUNT RATE	+10 %	7.0	↑
FAILURE RATE	+10 %	-0.6	↓
DIFFERENTIAL FAILURE RATES	+5 POINTS	-32.6	↕
DIFFERENTIAL DISCOUNT RATES	+1 POINT	-26.4	↕

\* RELATIVE TO MODEL ILLUSTRATED ON P. 6

SALVAGEABILITY NOTES FOR TOTAL LOSSES  
(POST-LAUNCH PHASE FAILURES)

<u>SPACECRAFT</u>	<u>FAILURE DATE</u>	<u>PHASE</u>	<u>SALVAGE DEGREE OF DIFFICULTY*</u>	<u>SALVAGE NOTES</u>
AYAME 2	02/25/80	2	2	BOOST REQUIRED; IN GTO
NOAA B	05/29/80	2	2	BOOST REQUIRED; IN POLAR
FLTSATCOM 5	08/06/81	2	5	EXTERNAL PHYSICAL DAMAGE; IN GEO
TDRS I A	04/04/83	2	2	BOOST REQUIRED; IN GTO
WESTAR VI	02/03/84	2	1	BOOST REQUIRED; IN LEO; RETREIVED 11/84
PALAPA B2	02/06/84	2	1	BOOST REQUIRED; IN LEO; RETREIVED 11/84
SYNCOM IV F3	04/13/85	2	1	BOOST REQUIRED; IN LEO
VORTEX	09/02/88	2	2	BOOST REQUIRED; IN GTO
GSTAR III	09/11/88	2	2	BOOST REQUIRED; IN GTO
INTELSAT VI F3	03/14/90	2	1	BOOST REQUIRED; IN LEO; REBOOSTED 5/92
INSAT I A	04/10/82	3	5	INTERNAL REPAIRS REQUIRED; IN GEO
BS 2A	01/23/84	3	5	INTERNAL REPAIRS REQUIRED; IN GEO
SYNCOM IV F4	09/05/85	3	5	INTERNAL REPAIRS REQUIRED; IN GEO
TVSAT 1	11/21/87	3	4	DEPLOYMENT REQUIRED; IN GEO
INSAT I C	07/29/88	3	5	INTERNAL/EXTERNAL REPAIRS REQUIRED; IN GEO
SOLAR MAXIMUM	12/12/80	4	2	INTERNAL (MODULAR) REPAIRS REQUIRED; IN LEO; REPAIRED 4/84
GOES 4	11/26/82	4	5	INTERNAL REPAIRS REQUIRED; IN GEO
NOAA E	07/01/84	4	5	INTERNAL REPAIRS REQUIRED; IN POLAR
GOES 5	07/30/84	4	5	INTERNAL REPAIRS REQUIRED; IN GEO
TELECOM I B	01/15/88	4	5	INTERNAL REPAIRS REQUIRED; IN GEO
GOES 6	01/27/89	4	5	INTERNAL REPAIRS REQUIRED; IN GEO
SUPERBIRD A	12/20/90	4	5	INTERNAL REPAIRS REQUIRED; IN GEO

\* 1 = EASY, 5 = VERY DIFFICULT







# **SELV-Based In-Space Operations Workshop**

## **Space Station Logistics Requirements**

105

**William M. Cirillo**

**NASA Langley Research Center**

**October 18, 1993**



## Logistics Areas Addressed by LaRC Analysis

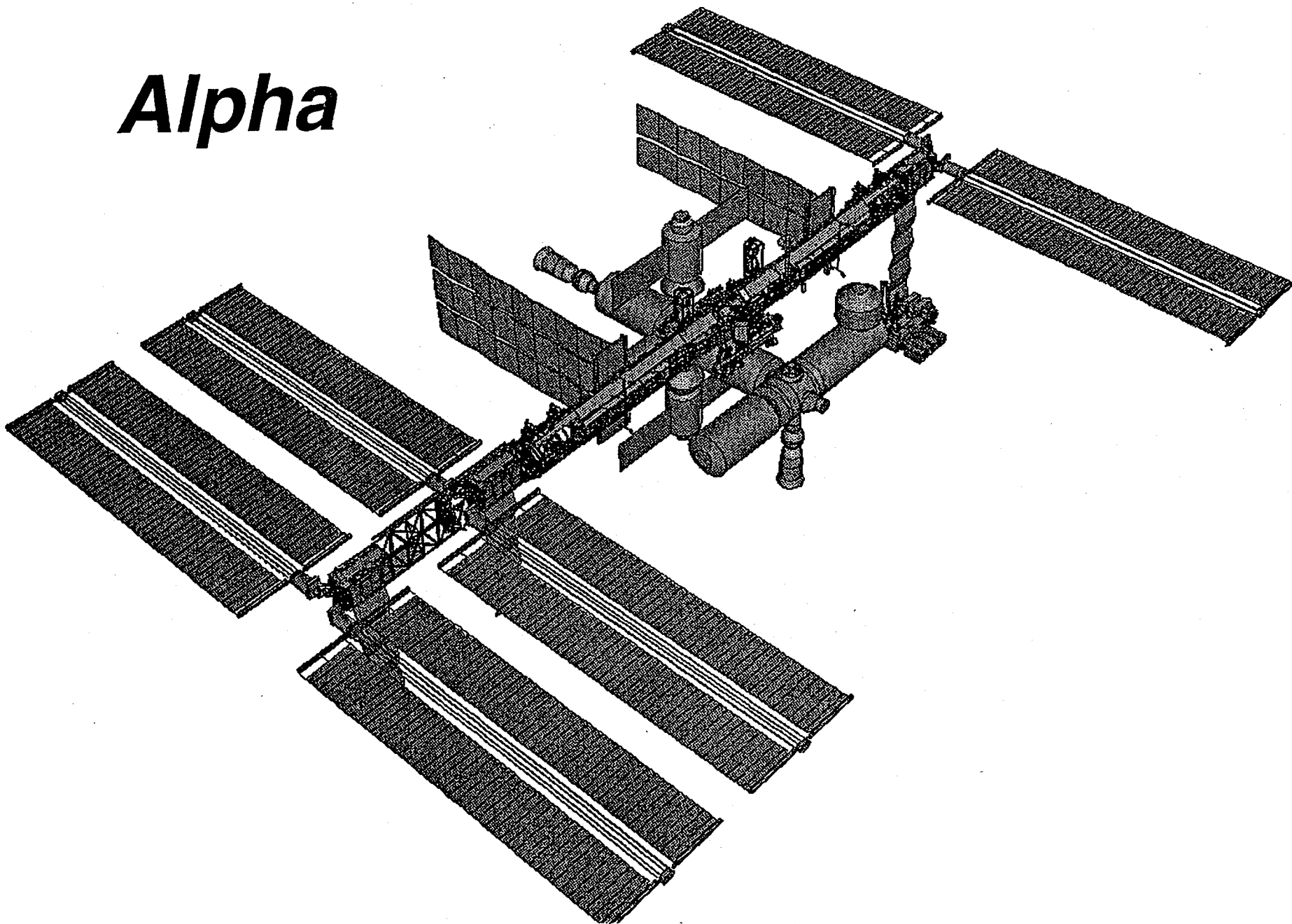
- **Assessment and verification of current Space Station logistics cargo requirements**
  - Option Alpha and Option Alpha with Russians
  - Reduction Options
- **Packaging Assessment**
  - Packaging requirements for each cargo discipline
  - Packaging detail from logistics element level to drawer level
- **Manifesting Analysis**
  - Logistics element delivery as a function of Shuttle performance capability
  - Mixed manifesting; cargo delivery by Shuttle plus ELV
  - Flight rates projected over an 11 year solar cycle
  - Options for return of ELV delivered cargo (volume, c.g. analysis)
- **Trash Assessment**
  - Identification of items to be returned or designated as “trash”
  - Implications of deviating from current “return all cargo” philosophy



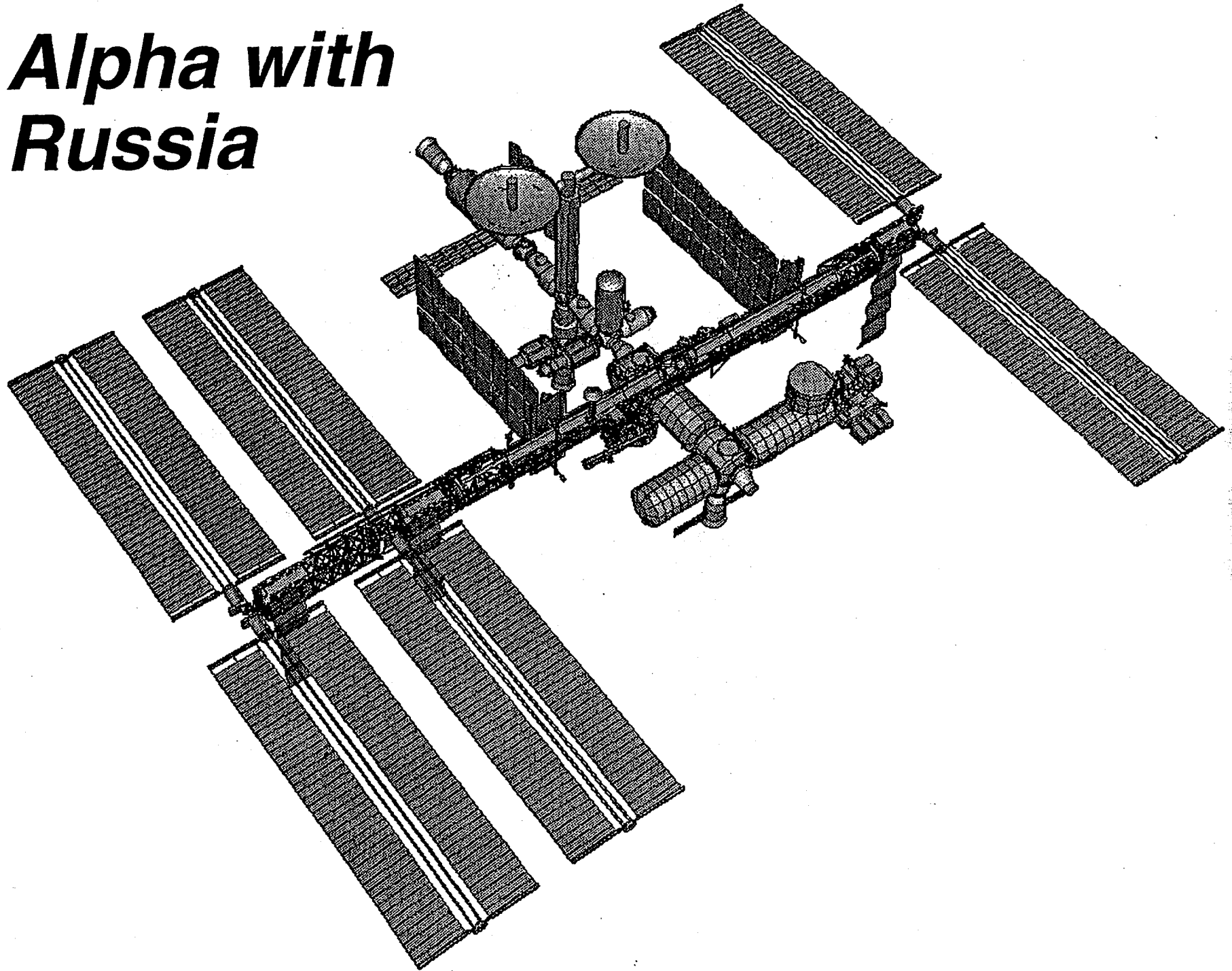
## Logistic Disciplines

- **Crew Systems**
  - Includes personal items, clothes, food, office supplies, film, etc.
  - Estimates based on analogs of previous JSC FCSD experience
- **Integrated Fluid Systems**
  - Comprises Hydrazine propellant and Cryogenic Oxygen/Nitrogen
  - Propellant estimates generated through PC based tool "STRAP"
  - Oxygen/Nitrogen estimates based on data provided in the ECLSS ACD
- **Spares/Maintenance**
  - Comprises ORUs required due to routine maintenance or failure
  - Estimates based on predicted number of maintenance actions (RMAT) and most recent Work Package ORU data (AMIDD)
- **Users**
  - Comprises user experiments, small equipment, and samples
  - Based on in-house analysis of available user databases projecting experiment compliments while maintaining balanced resources (crew/power/volume) for a variety of emphases

# *Alpha*

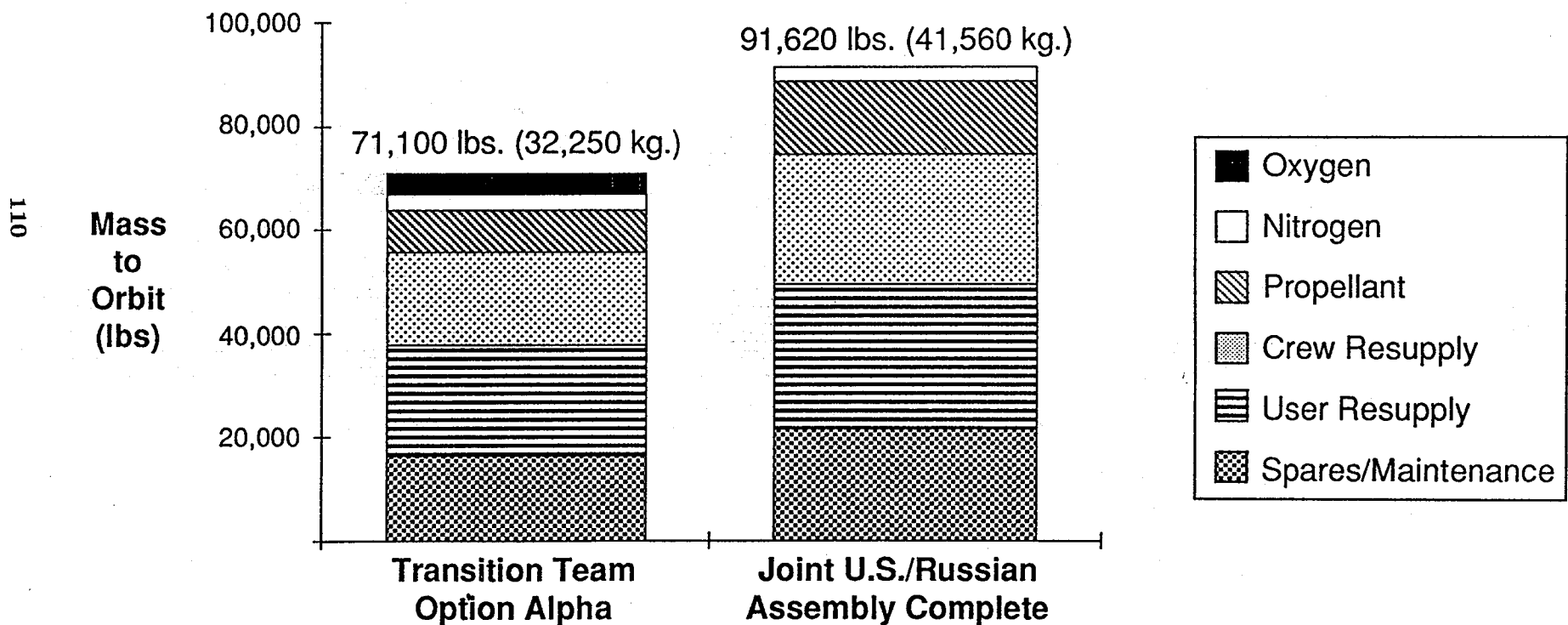


# ***Alpha with Russia***





# Space Station Average Annual Logistics Resupply Requirements (Carriers not Included)





## Space Station Average Annual Logistics Resupply Requirements Detail (Carriers not Included)

Cargo	Option Alpha	U.S./Russian
Spares	16,260	21,490
Scientific Resupply	21,450	28,060
Crew Resupply	18,000	25,200
Propellant Resupply	8,230	13,970
Nitrogen	2,900	2,900
Oxygen	4,260	0
Total	71,100	91,620



## Late/Early Access and Climate Controlled Requirements

- Current late/early access and climate control requirement estimates are based on projected Code U and OACT payloads
- Maximum annual user requirement is 284 Shuttle middeck lockers (14.3 equivalent racks)
- User middeck locker requirements are based on the following needs\*:
  - Late access 15-24 hours prior to launch (171 MDLs delivery)
  - Early access 2-4 hours following landing (158 MDLs return)
  - Animal habitat/holding facilities (14 MDLs delivery, 3 MDLs return)
  - On-Orbit power (117 MDLs delivery, 102 MDLs return)
  - Refrigeration to 4° C (42 MDLs delivery, 53 MDLs return)
  - Freezers from -20° C to -195° C (11 MDLs delivery, 29 MDLs return)
- Crew CHeCS currently requires one middeck locker per year
- Middeck locker requirements for crew supplies is currently TBD

\* Middeck locker requirements are in some cases overlapping and not additive

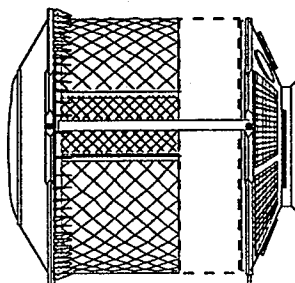




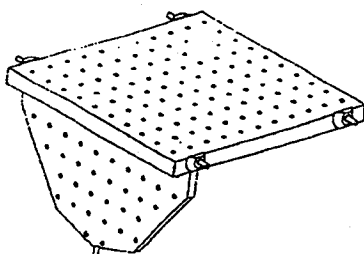
# Logistics Element Overview (Option Alpha)

## Elements

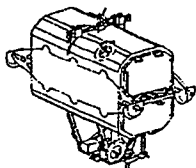
16-Rack  
Mini-Pressurized  
Logistics Module  
(MPLM)



Unpressurized  
Logistics Module  
(ULC)



Propellant  
Module (PM)  
or  
Space Tug



## Subelements

- Resupply/Storage Racks
- Payload (User) Racks
- Refrig/Freezer Racks
- Aisle Stowage

- Cryo Nitrogen Carrier
- Cryo Oxygen Carrier
- Dry Cargo Carrier (DCC)

None

## Cargo

- Internal Users
- Crew Systems
- Spares/Maintenance

- Cryogenic Fluids
- External Users
- Spares/Maintenance

- Hydrazine  
Propellant



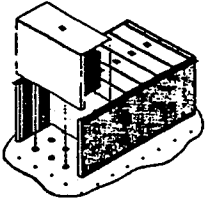
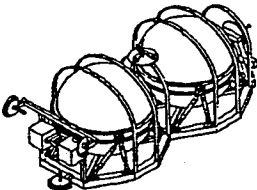
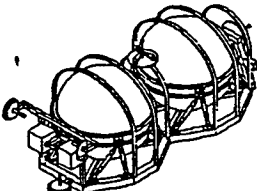
## Logistics Element Overview (Option Alpha)

### Pressurized Subelements - Racks & Lockers

	<u>Subelements</u>	<u>Number Required</u>	<u>Cargo</u>
	Resupply/Storage Racks	44	<ul style="list-style-type: none"><li>• Internal Users</li><li>• Crew Systems</li><li>• Spares/Maintenance</li></ul>
114	Aisle Stowage Containers	20	<ul style="list-style-type: none"><li>• Crew Systems</li></ul>
	Refrigerator/Freezer Racks	6	<ul style="list-style-type: none"><li>• Crew Systems</li></ul>
	Integrated Standard Payload Racks (ISPRs)	3	<ul style="list-style-type: none"><li>• User payloads</li></ul>
	Shuttle Middeck Lockers	142	<ul style="list-style-type: none"><li>• User Logistics</li><li>• Crew Systems</li></ul>



## Logistics Element Overview (Option Alpha) Unpressurized Logistics Carrier Subelements

<u>Subelements</u>	<u>Number Required</u>	<u>Cargo</u>
Dry Cargo Carrier (DCC) 	4	• Spares/Maintenance
Cryogenic Nitrogen Carriers 	2-3	• Cryogenic Nitrogen
Cryogenic Oxygen Carriers 	2-3	• Cryogenic Oxygen

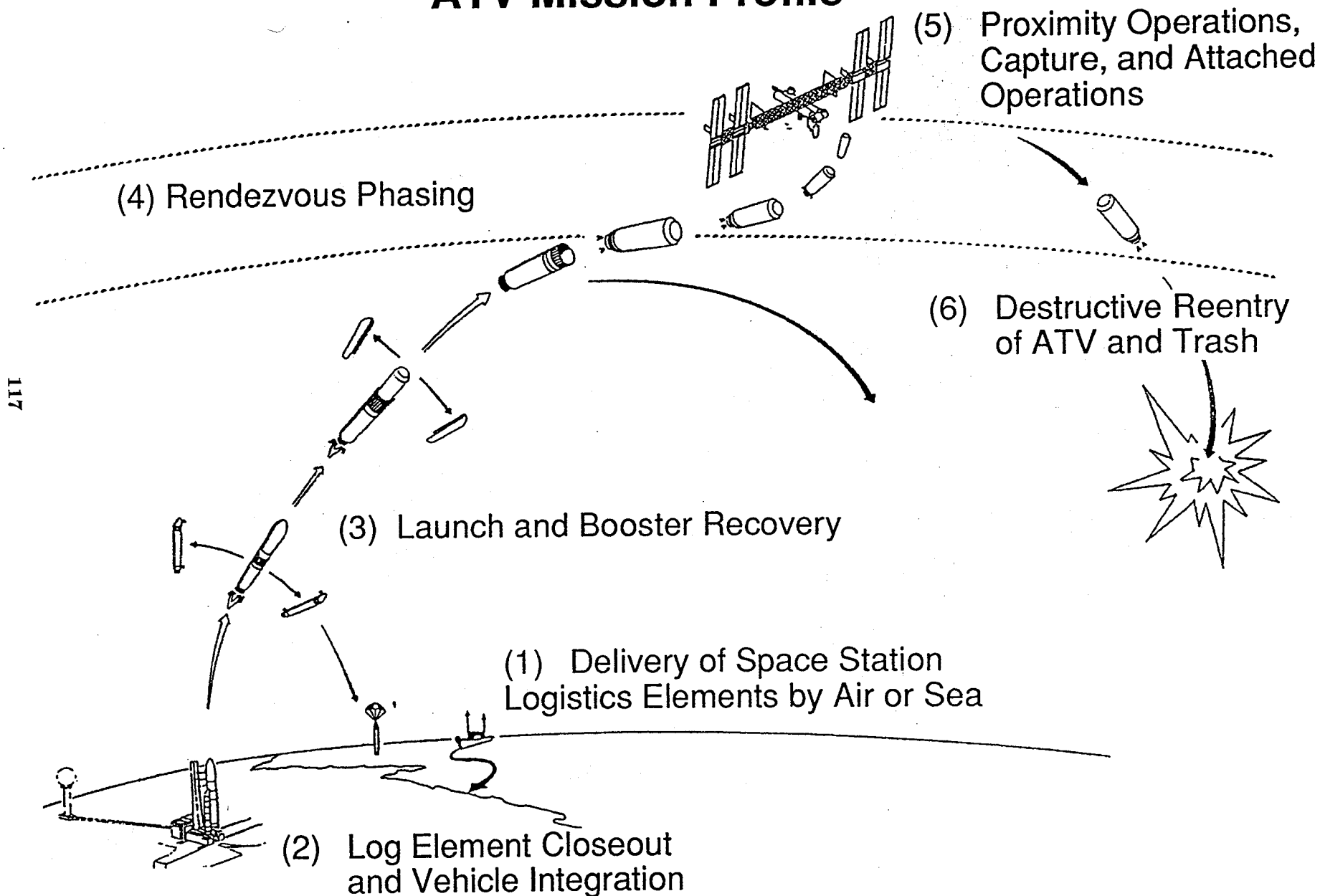


## ESA ATV Utilization Background

- The ESA Automated Transfer Vehicle (ATV) is a proposed orbital transfer stage which will provide automated rendezvous capability for the Ariane 5 launch vehicle
- In December, 1992, NASA and ESA initiated a joint study to assess the feasibility of using the ATV for logistics resupply of the U.S. space station
- This paper presents initial results of a NASA Langley Research Center study to define and evaluate *ATV design reference missions*
  - Space Station logistics cargo options
  - ATV cargo integration concepts
  - Ground processing issues associated with transcontinental shipping and closeout of Space Station cargo at the Guyana Space Center (CSG)
  - Space Shuttle + Ariane 5/ATV flight operations issues



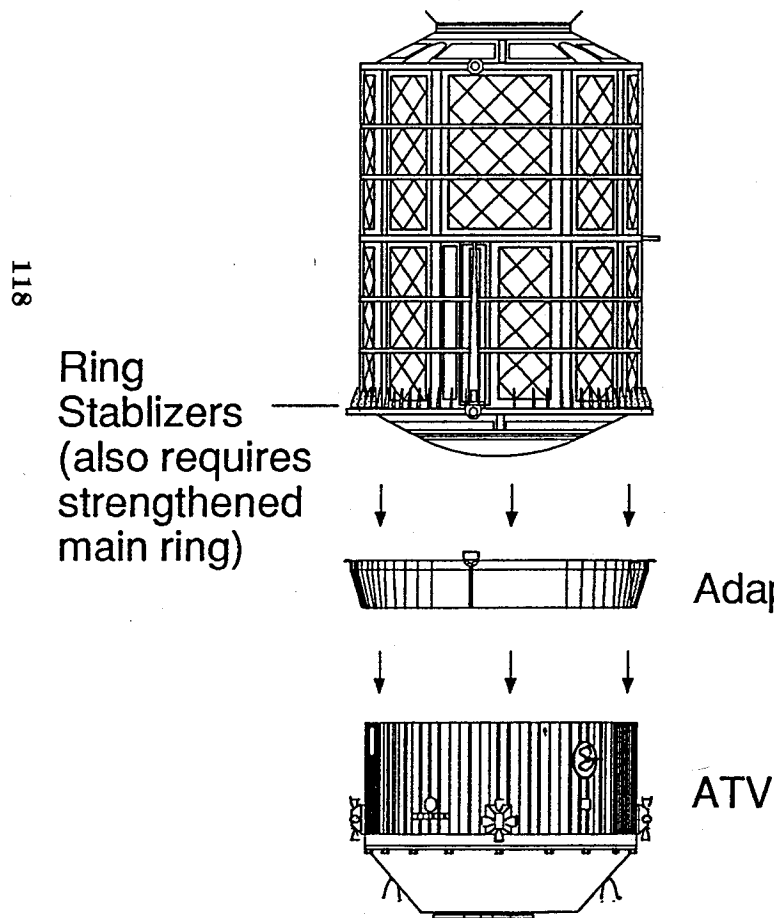
## ATV Mission Profile



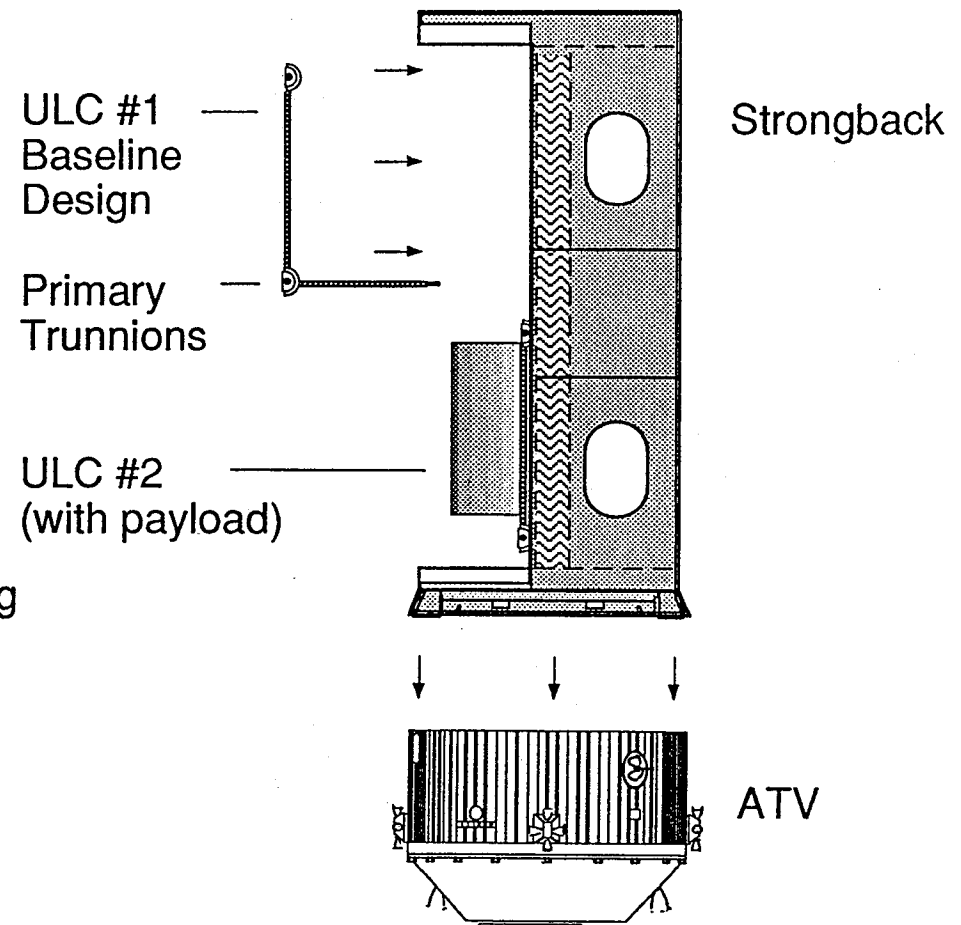


# Logistics Element-to-ATV Integration Concepts

## Pressurized Logistics Module (PLM)



## Unpressurized Logistics Carriers (ULCs)





# Summary of ATV DRM Cargo Options for Space Station Freedom Logistics Resupply

## Pressurized Cargo

- 1 Active Mini-Pressurized Logistics Module (MPLM)
- 1 Inactive MPLM
- 1 Active Pressurized Logistics Module (PLM)
- 1 Inactive, Disposable MPLM (*conceptual*)

## Unpressurized Cargo

- 1 Unpressurized Logistics Carrier (ULC)
- 2 ULCs
- 1 Elongated ULC (*conceptual*)

## Propellant

- 2 Propulsion Modules (PMs)

## Mixed Cargo

- 1 Inactive MPLM + 1 ULC
- 2 PMs + 1 ULC
- 2 PMs + 1 Inactive MPLM
- 1 Inactive, Disposable MPLM + 1 ULC



## Drivers for ATV Cargo and Flight Rate Recommendations

- **Ground Processing Requirements at Guyana Space Center (CSG)**
  - Complexity of cargo closeout operations
  - Requirements for new facilities or equipment
- **ATV to Cargo Integration Requirements**
  - Compatibility of baseline logistics elements
  - Requirements for new logistics elements or ATV interface hardware
- **Integrated Space Shuttle + Ariane 5/ATV Transportation Considerations**
  - One-to-one Shuttle flight savings per Ariane 5/ATV flight
  - SSF cargo disposal requirements vs. trash availability
  - Ariane 5/ATV performance margin





## Summary of Preliminary Results

- Six scenarios for ATV cargo delivery have been identified as feasible considering Shuttle + Ariane 5/ATV transportation and ground processing issues
  - 4 cargo options assuming 1 ATV flight per year
  - 2 cargo options assuming 2 ATV flights per year
- Ariane 5/ATV flight support greater than two per year does not appear viable due to limitations in cargo return capability
- ATV delivery of a PLM at a rate of one per year appears to be the most desirable scenario for Ariane 5/ATV support
  - Supports "Ship and Shoot" philosophy
  - Minimal modifications required for Ariane 5/ATV compatibility
- Ariane 5/ATV delivery of Propulsion Modules is *not* considered viable by NASA due to numerous issues associated with *transcontinental* ground processing



## Russian Vehicle Studies

- **Joint studies on the use of Russian vehicles in support of Space Station have taken place through three forums:**
  - NASA contract with NPO Energia (6/92 - 4/93)
  - Space Station Redesign Team (5/93)
  - Space Station Transition Team (8/93)
- **Major Objectives:**
  - To gather and review technical data on existing and modified Russian transport and launch vehicles
  - To assess the feasibility of using these vehicles for logistics resupply and crew rotation of a joint US/IP/Russian Space Station
  - To determine the benefits of a mixed fleet manifesting approach
- **Results to date include identification of options for logistics resupply of Space Station using Russian vehicles in two broad categories:**
  - Use of existing and modified Russian transport vehicles for delivery of U.S. cargo at the sub-element level
  - Delivery of U.S. logistics elements using Russian transfer vehicles

# **SESSION II**



# **Summary of the SELV-Based In-Space Operation Workshop**

## **October 18-19, 1993**

### **Hampton, VA**

#### **SESSION II**

Jack Koletty, EER, Inc.

Jack gave a presentation of EER's SELV launch system family. He identified three primary systems:

- Space Systems
- Information Systems
- Training Systems

EER has had six launches to date out of White Sands. The longest part of the presentation was on the Conestoga (which means covered wagon) launch vehicle family. Main features of the Conestoga are: (1) continuous and flexible size selection for payloads from 500 to 4700 pounds ; (2) common motor emberfamilies for all configurations; and, (3) fairing design and range of standard lengths offer users a variety of size and access options. A video was presented which showed three development tests: (1) wind tunnel test; (2) engine firing test; and, (3) fairing separation test. They claim that they can launch a vehicle in 30 days, and the first launch is set for February 1994.

Larry Langston, Lockheed Missiles and Space Company

Lockheed has directed the launching of more than 300 vehicles. Larry talked about the Lockheed Launch Vehicles (LLV). The LLV designs are based on Lockheed's experience with

the Polaris SLBM. There are three LLV's that have capacities of 1, 2, and 4 tons. Lockheed's goal for first launch of the LLV1 is set for November 1, 1994. They do not have a payload yet for the November flight. He said that they are still on target for meeting the launch date, and that they want a payload by next month. The guidance, navigation, and control is being purchased from other contractors.

#### Pat Albert, Martin Marietta

Pat's presentation was on the Martin Marietta MSLS launch system. This vehicle is based on a converted Minuteman ICBM and can handle payloads of up to 800 pounds. One feature of the vehicle is that half the shroud can be easily removed and the payload accessed. The Minuteman vehicles are owned by the DoD and are only available to other U.S. government agencies. Hence, there is no reason for a commercial industry to come to Martin for a launch.

#### Chris Schade, Orbital Science Corporation

Chris talked primarily about Pegasus, with some comments on Taurus, too. Pegasus can handle payloads of up to 1000 pounds, with a launch price of \$8 - 12 million. The payload bay is 75 inches long and 46 inches in diameter. Pegasus is launched from an airplane allowing for twice the payload to be handled as with a ground-based launch. A video accompanied the presentation. The Taurus rocket is a ground-launched, modified Pegasus.

#### Mike Dobbs, ERIM/SPARC

Mike's talk was on the Space Automation and Robotics Center technology development are working on Rendezvous and Docking of a chaser vehicle with a target vehicle. They have combined autonomous rendezvous and docking on a Ranger system. They expect to fly the

target vehicle in FY94 and the chaser vehicle in FY96. They are currently shopping for a launch vehicle.

Ralph Will, NASA Langley

Ralph discussed past and present robotics systems applicable to SELV's. He said that there is lots of technology available in robotics, but that none of the technology is specific, nor has it been flight tested. There have not been any flight tests because there is no customer yet. He commented that it must be shown that robotics meet or exceed the capabilities of the alternatives.

Dan Moerder, NASA Langley

Discussed current efforts in rendezvous and docking of two vehicles in space. The approach is to develop highly automated generic tools.

Ray Montgomery, NASA Langley

Mentioned that standardization of computers, software, devices, etc. is one of the most important issues to address.

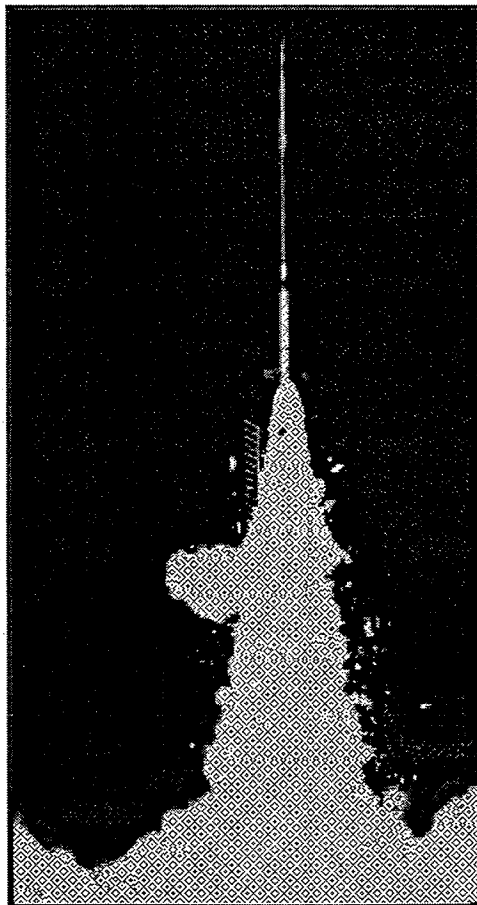
Kevin Dutton, NASA Langley

Kevin presented some initial studies on GPS systems. One question that arose is the reliability of GPS. He responded that there are enough satellites so that at any time and any place, there are the necessary four satellites for position sensing.

### Steve Thibault, CTA Launch Systems

Steve mentioned that CTA used to be International Microspace. His talk was on the CTA/ORBEX launch system. They were able to launch a vehicle 360 days after a contract at a cost of \$4 million. The corporate vision is to offer data services.





**Starfire**  
Suborbital



**Conestoga**  
Orbital

**EER Systems**  
**Space Products Group**  
**Offers**  
**"Vehicles of Choice"**

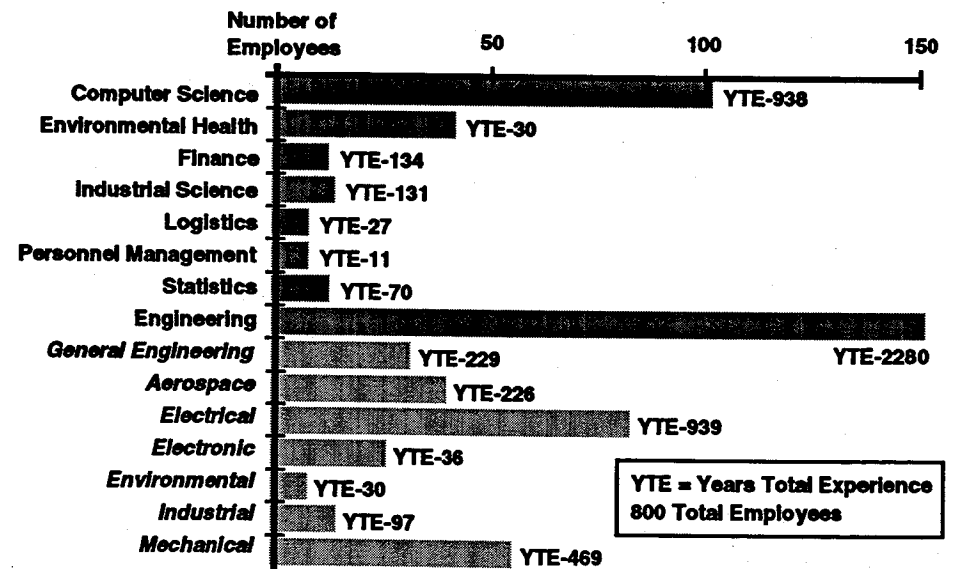
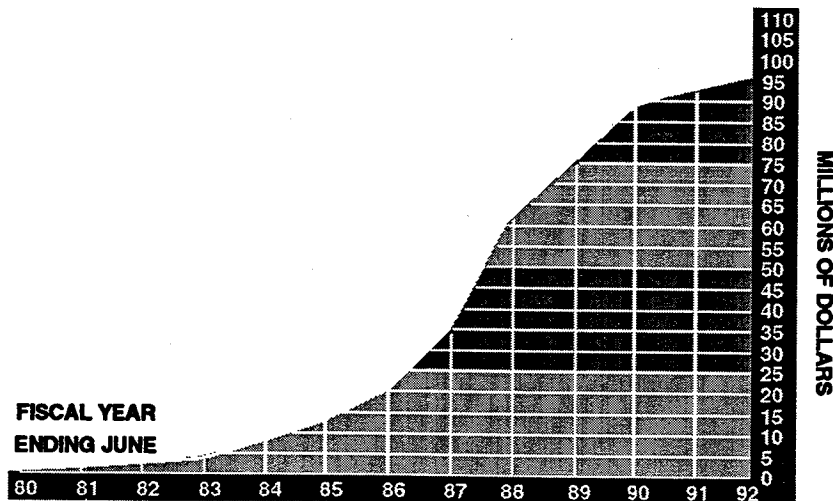
**October 1993**

- Introduction
- EER Systems Corporation
- Conestoga Fleet of ELV's
- Integration & Test Program
- Performance
- Launch Operations
- Current Programs
  - COMET
  - MSTI-5
- Summary

# "Vehicles of Choice"

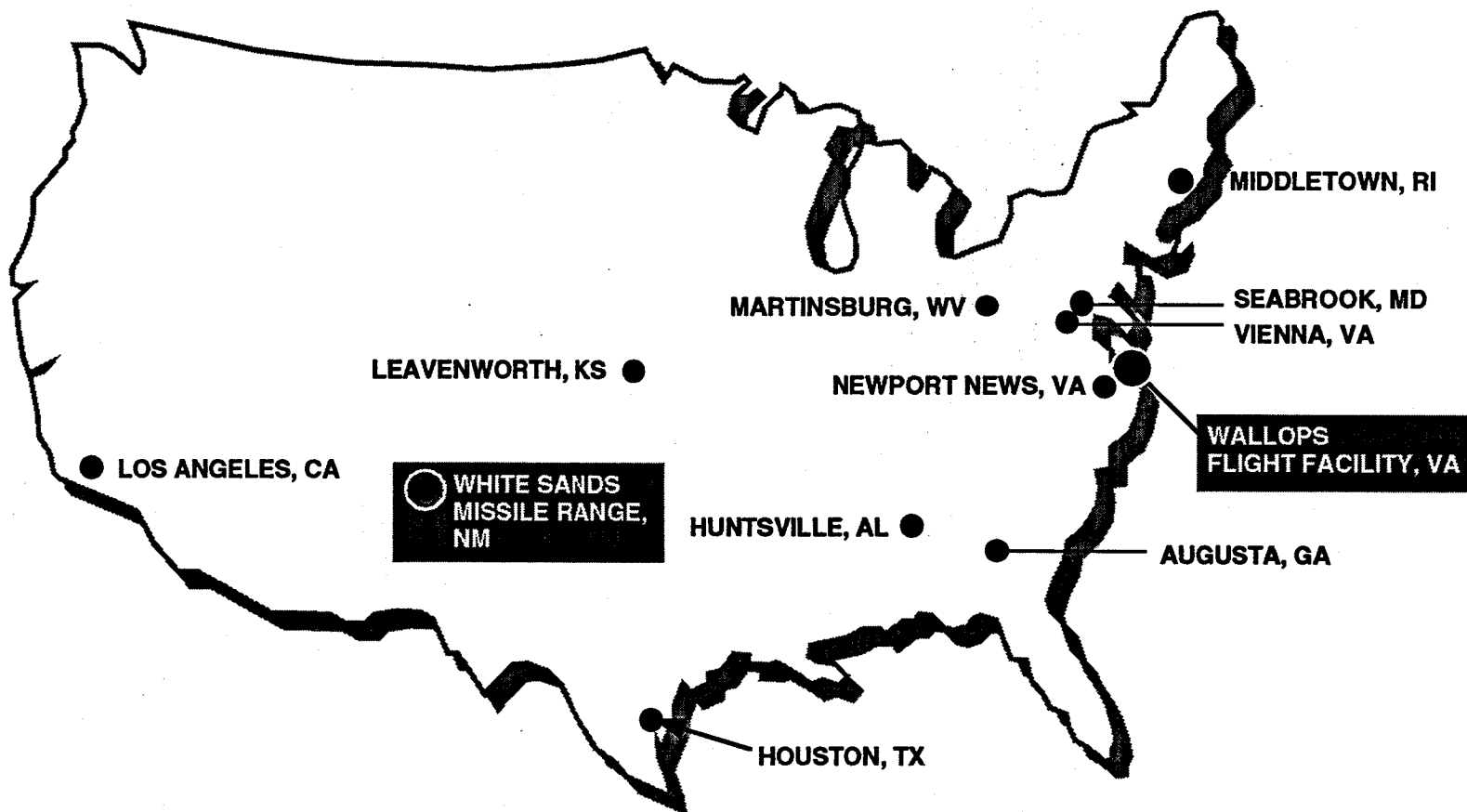
## Corporate Profile

- EER Systems Is an Aerospace and Defense Company
  - Headquartered in Vienna, Virginia
  - Fourteen Years of Sustained Growth
    - Space Systems
    - Information Systems
    - Training Systems
  - Facilities Nationwide
  - Offering Suborbital and Orbital Launch Vehicles to a Broad Base of Customers



# "Vehicles of Choice"

## Office Locations



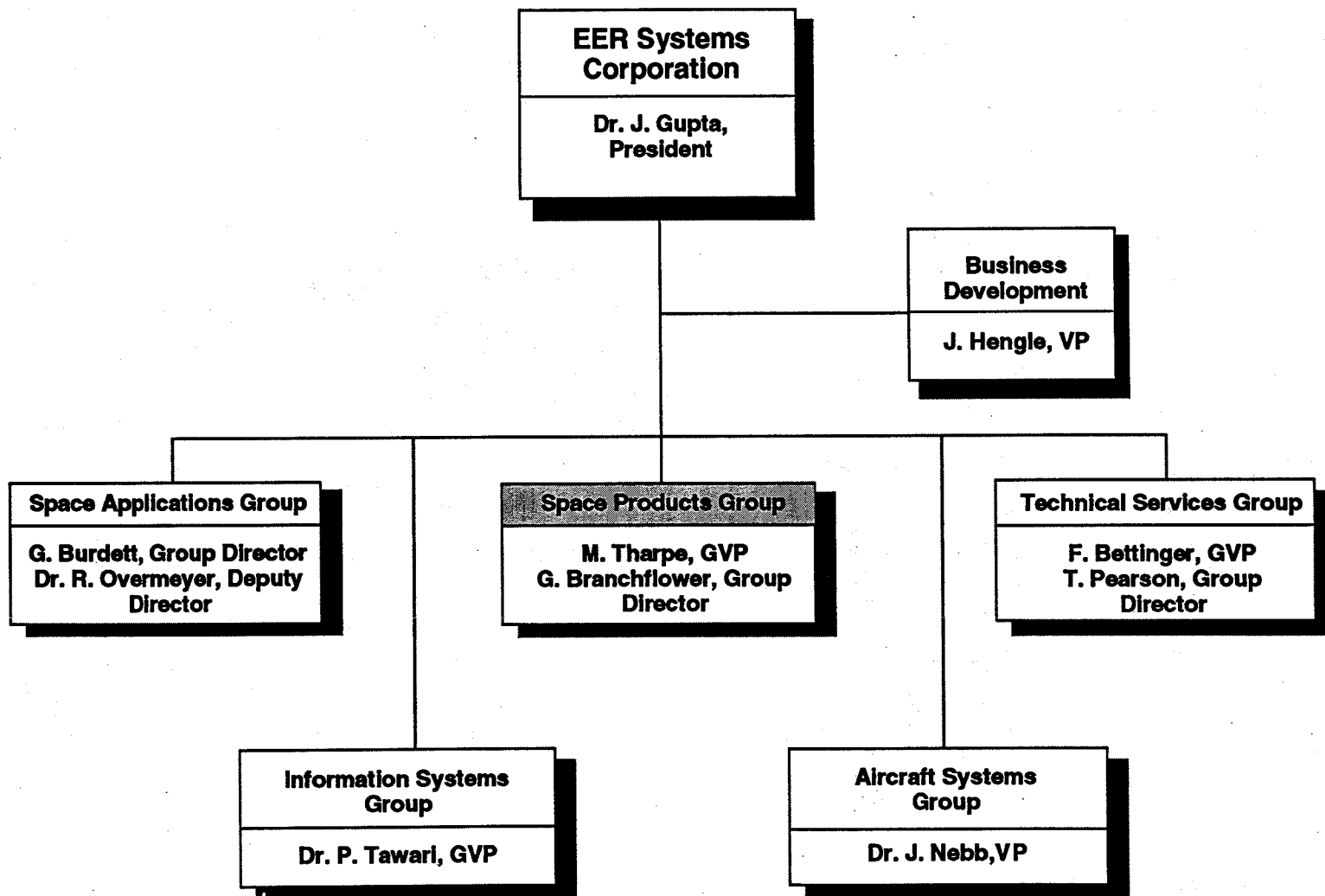
### ADDITIONAL LOCATIONS :

Crystal City, VA  
Ft. Benjamin Harrison, IN  
Washington, DC

Ft. Gordon, GA  
Ft. Monmouth, NJ  
Ft. Washington, PA

Tobyhanna, PA  
Lorton, VA  
MacDill AFB, FL  
Monterey, CA

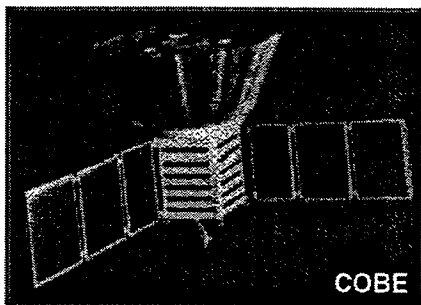
San Diego, CA  
Zweibrucken,  
Germany  
Ft. Chaffee, AR



# "Vehicles of Choice"

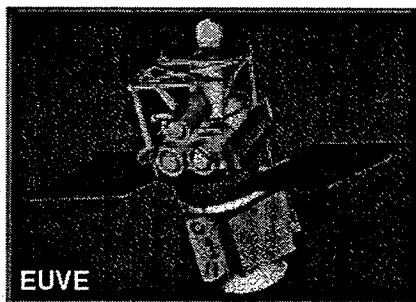
## Space System Groups Profile

### Applications Group

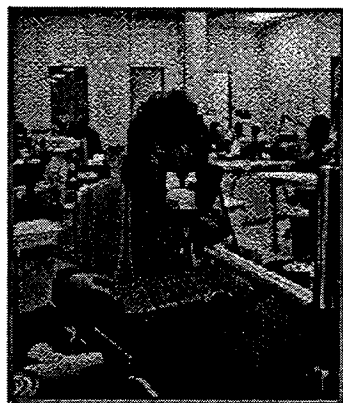


**Explorer Platforms**

- **System Engineering**
  - Mechanical
  - Thermal
  - Electrical
  - Software
  - Optics
  - Experiment Management

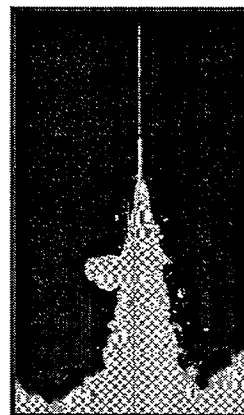


- **Subsystem Development**
  - Design and Development
  - Integration and Test
  - Program Management Support



- **Electrical and Mechanical Fabrication and Assembly**
  - MIL-STD-Compliant
  - Prototyping and Limited Production

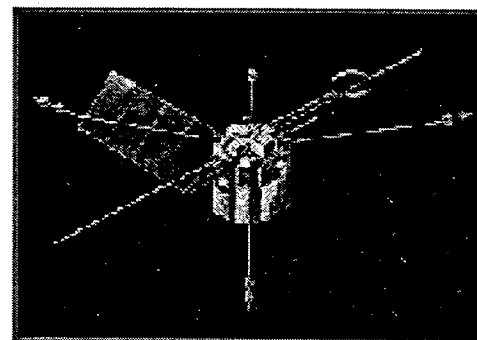
### Products Group



**Starfire – Suborbital**



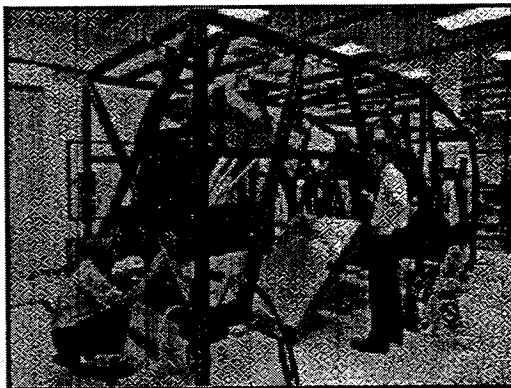
**Conestoga – Orbital**



**EER Small Satellite  
Bus Development**

# "Vehicles of Choice"

## Selected Corporate Experience



**MH-53J Maintenance Trainer**

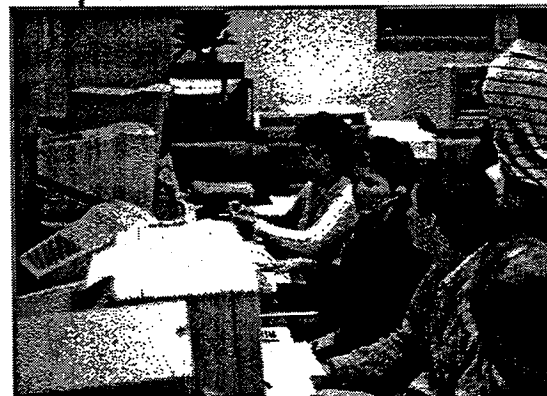
- **GPS Real-Time Display Systems**
  - Distributed Systems
  - Development and Fabrication
  - Installation and Maintenance



**MH-53J Helicopter**

- **Aircraft Modification and Upgrades**
  - System Design Development and Fabrication
  - Human Factors Engineering
  - Communications/Navigation Processors
  - Computer and Multifunction Displays
  - Global Positioning System Integration

- **Traffic Management Systems**
  - Review and Analysis of Design Documentation and Code
  - Ada Software Development
    - Real-Time Systems
    - DOD-STD-2167A
- **IV&V of Operational Software**
  - AAS Control System
  - V22 Aircraft

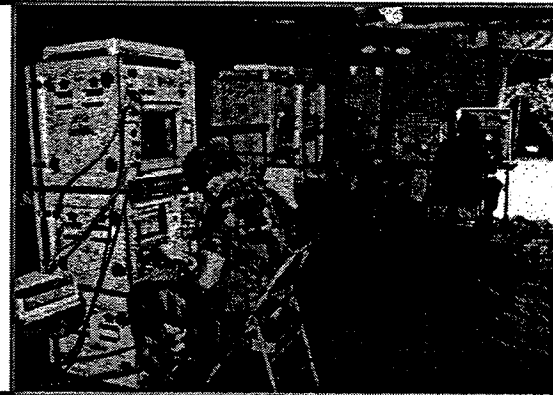


**Vessel  
Tracking  
Service**

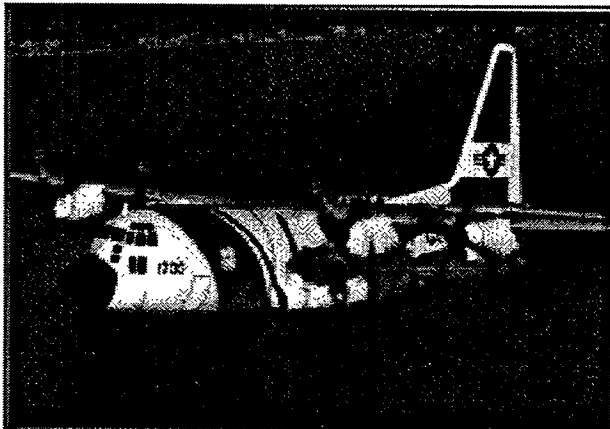
# "Vehicles of Choice"

## Selected Corporate Experience

- **Command and Control**
  - Enhanced Tracking for the Advanced Range Data System
  - Air Defense Software Maintenance – Hawk Missiles
- **Combat Training Centers**
  - Base and Mobile Communications System
  - Field Data Collection System
  - Real-Time Exercise Analysis and Control
  - Training Analysis and Feedback



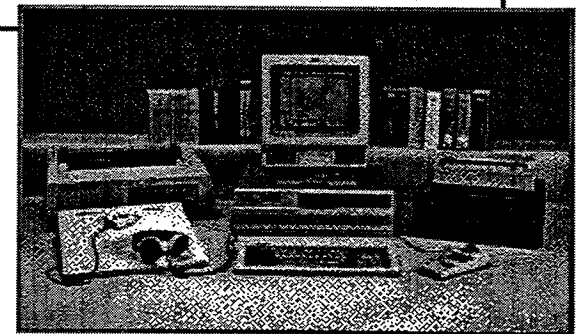
**Combat Maneuvering Training Complex**



**C-130 Aircraft**

- **Computer-Based Instructional Training Applications**
  - Courseware Development
  - System Development and Integration
  - Standalone/Networked Workstations
  - Course Delivery and Evaluation
  - Logistics

- **C-130 Surveillance Systems**
  - Drug Smuggling/Search and Rescue Operations
  - Design, Development, and Fabrication of System Components
  - Configuration Audits

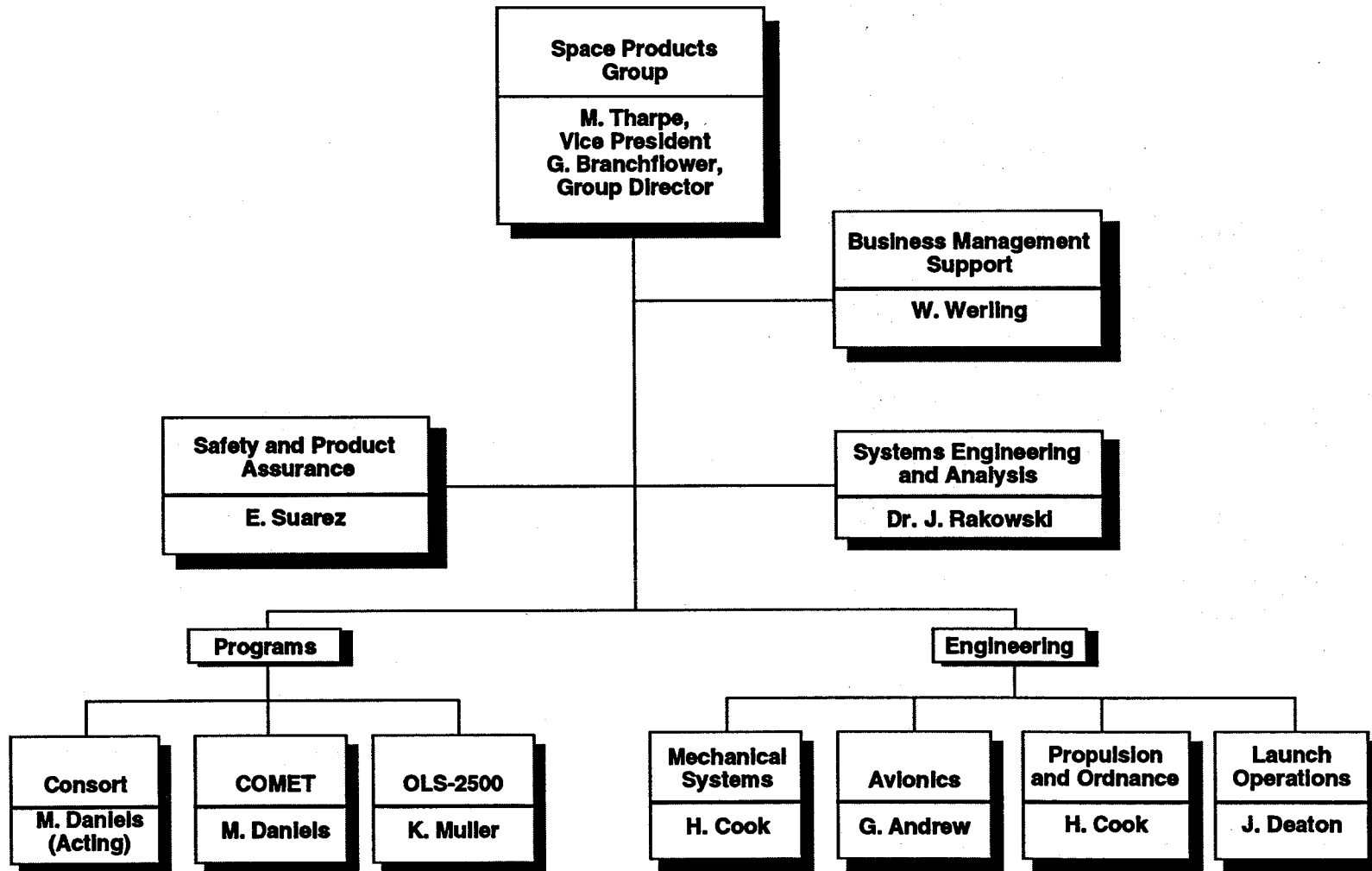


**F-15 and F-16 Aircraft Computer-Based Instructional Training System**



# "Vehicles of Choice"

## Space Products Group Functional Organization



# "Vehicles of Choice"

## Starfire I Suborbital Consort Program

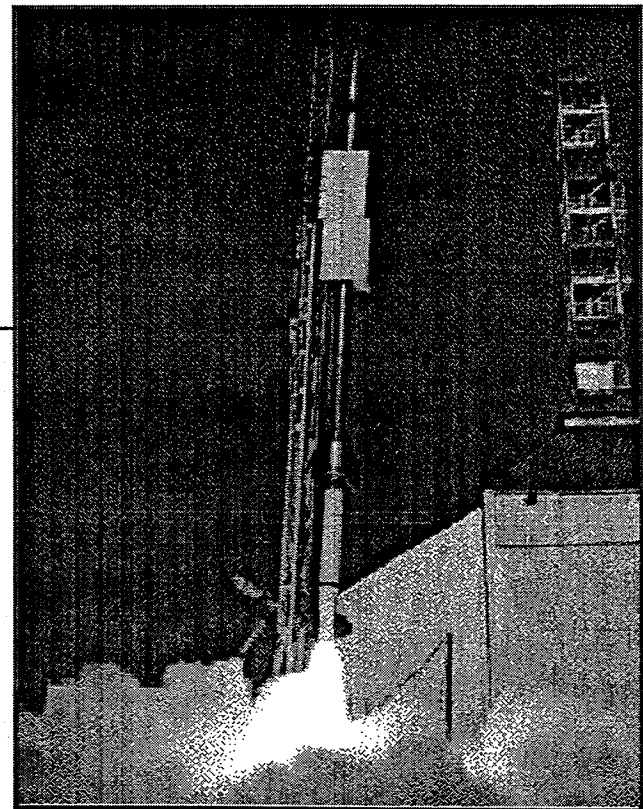
### Consort Requirements:

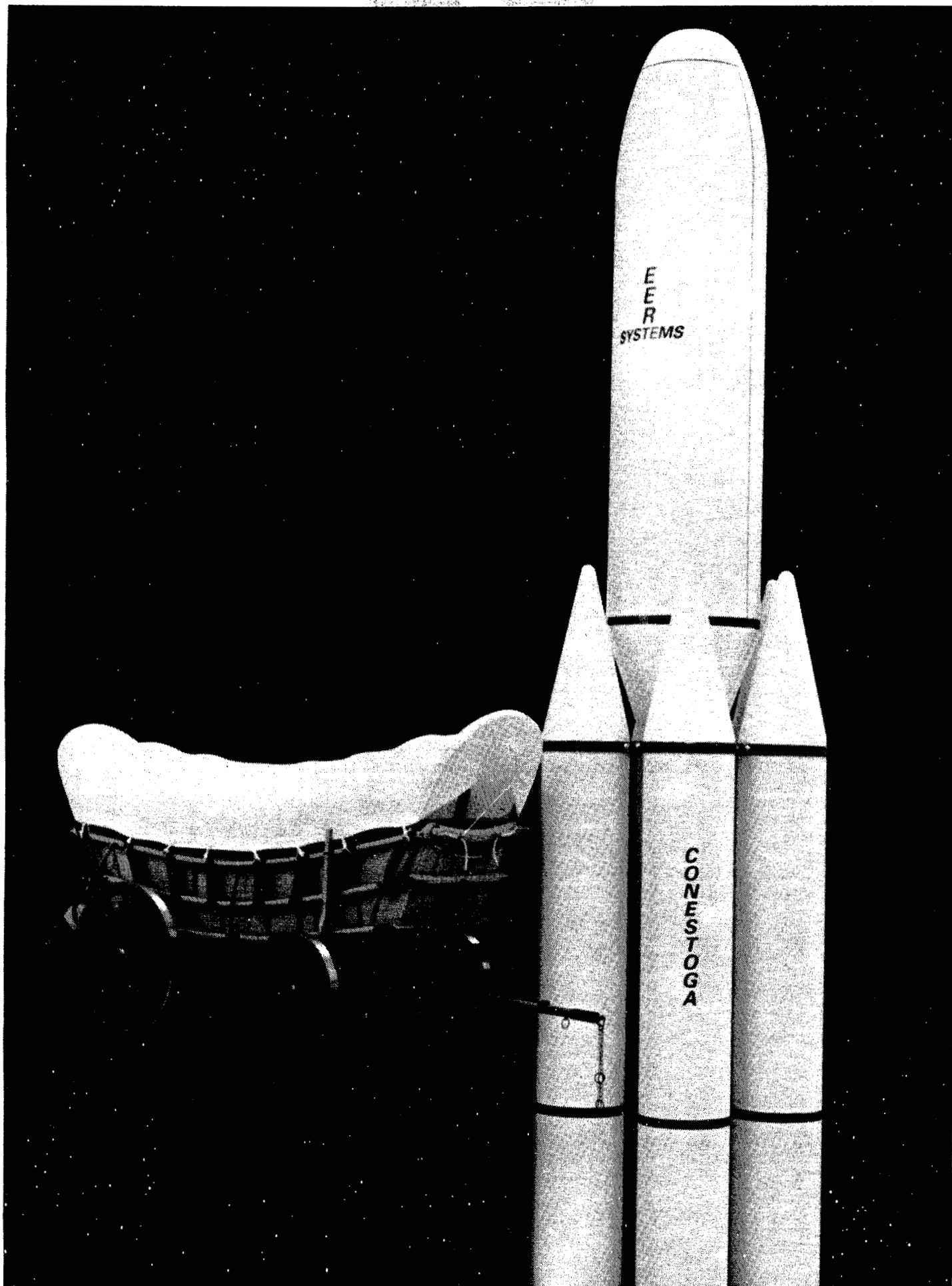
- Microgravity Level of  $10^{-4}$
- Payload Weight of ~ 1000 Pounds
- Microgravity Time of ~ 7.0 Minutes
- Recoverable Payload
- Reusable Components: Guidance Control Subsystem, Rate Control Subsystem, Telemetry Subsystem, and Recovery Subsystem

### Consort Launches

- 1 March 29, 1989
- 2 November 15, 1989\*
- 3 May 16, 1990
- 4 November 16, 1991
- 5 September 10, 1992
- 6 February 19, 1993

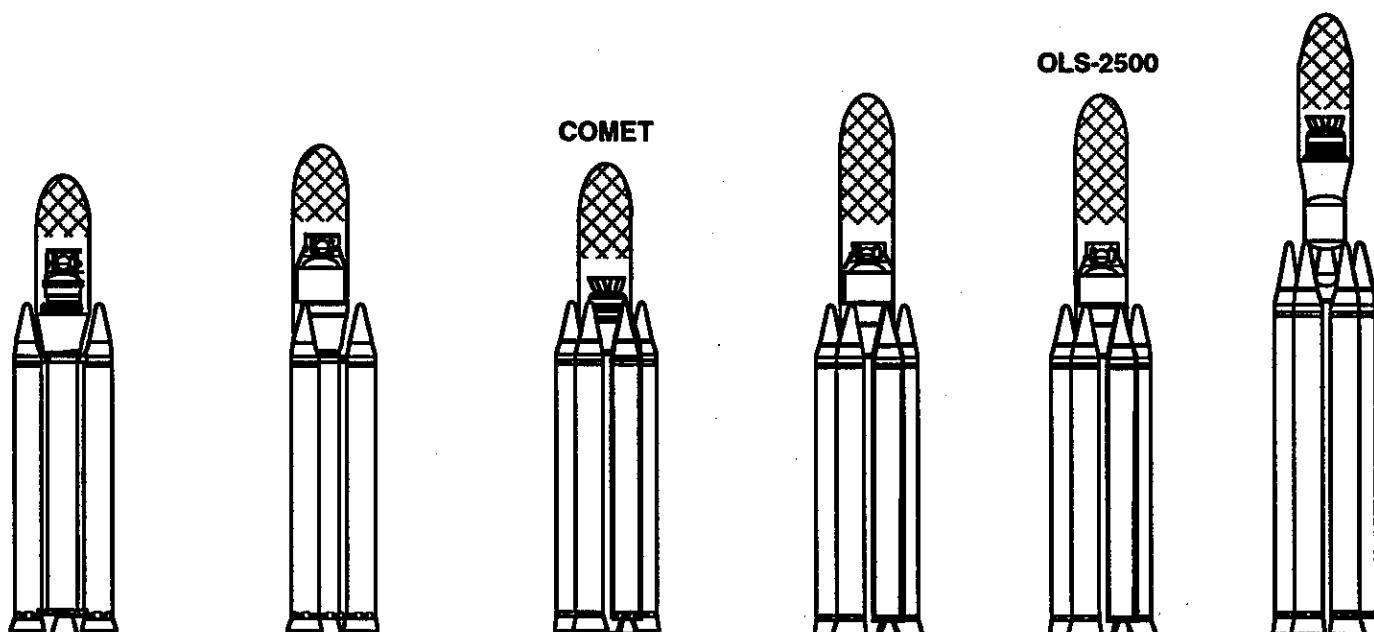
\*Partial Success (Payload Recovered)





# "Vehicles of Choice"

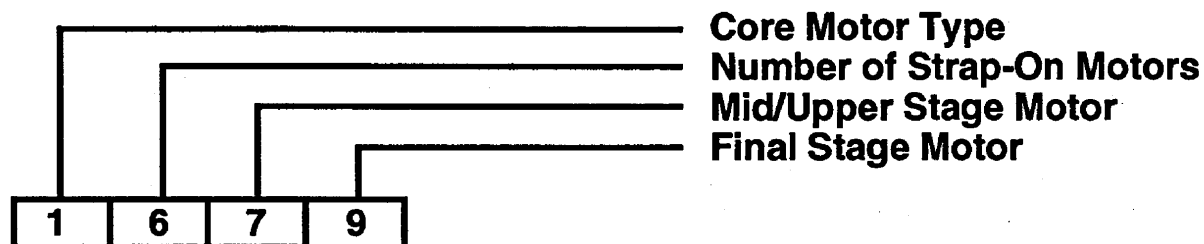
## Conestoga Modular Fleet Meets Broad Range of Requirements



Model	1229	1379	1620	1669	1679	3632
Performance (lbs)						
LEO (I = 38°) (100 NM CIRC)	800	1700	2600	3000	3300	4720
POLAR (I = 90°) (100 NM CIRC)	650	1300	2200	2450	2750	3820

# "Vehicles of Choice"

# Conestoga Model Identification System



- First digit identifies the motor used as the core (center) motor and is defined as:

1 — CASTOR IVB  
3 — CASTOR IVB XL  
5 — GEM VN

- Second digit designates the number of strap-on motors.

- Third and fourth digits identify the motor used for mid- and upper stages and are defined as:

0 — No Stage Motor	5 — (unassigned)
1 — STAR 37 FM	6 — STAR 63D
2 — STAR 48V	7 — STAR 63F
3 — Orion 50XL	8 — (unassigned)
4 — (unassigned)	9 — Liquid Transfer Stage

# **"Vehicles of Choice"**

## **Conestoga Features**

- **Straightforward Modular Design**
  - "Parallel" Approach Provides Robust Vehicle
  - Capable of Being Launched in Most Weather Conditions
- **One Vehicle Design Concept Supports a Wide Range of Payload Weights**
  - "Right Sizing" of Vehicle to Meet Cost, Payload, and Mission Needs
  - Modular Mission Sizing Up to over 4700 Pounds in LEO
  - Common Motors for All Configurations
- **High Marks in Reliability**
  - Unmatched Motor Heritage (Thiokol CASTORs and STARs)
  - Most Vehicle Components Are Off-the-Shelf
- **Guidance Navigation and Control System**
  - Orbital Insertion Accuracy (3-Sigma Dispersions) Altitude  $\pm 20$  nmi; Inclination  $\pm 0.20^\circ$
  - Accuracy With H-MACS and a  $1\sigma$  IMU (3-Sigma Dispersion) Altitude  $\pm 10$  nmi; Inclination  $\pm 0.05^\circ$
- **Range of Standard Payload Fairings**
  - Largest Diameter Available in Weight Class (72")
  - Length Varies From 12' to 24'
- **Portable Service Tower**
  - Ability to Launch From Almost Any Range
  - Clamshell Design Offers Controlled Integration Environment
  - Convenient Late Access to Payloads
  - Services All Conestoga Vehicle Designs

# "Vehicles of Choice"

Conestoga Heritage

<u>Company</u>	<u>Component</u>	<u>Similar Programs Supported</u>
LOGICON/ Control Dynamics	Guidance, Navigation, and Control Analysis	<ul style="list-style-type: none"> <li>• Space Shuttle GN&amp;C</li> <li>• Minuteman &amp; Peacekeeper IV&amp;V</li> </ul>
TRACOR Aerospace	Payload Fairing	<ul style="list-style-type: none"> <li>• Minuteman and Polaris Shrouds</li> <li>• Numerous Missile Deployment Systems</li> </ul>
Scot, Inc.	Stage Attach/Separation H/W	<ul style="list-style-type: none"> <li>• Atlas IIAS Attach/Separation Systems</li> </ul>
Altair Aerospace Corp.	Ground Software	<ul style="list-style-type: none"> <li>• Titan</li> </ul>
Mutual Tool & Die	Fabricated Components	<ul style="list-style-type: none"> <li>• Space Shuttle</li> <li>• Apollo</li> <li>• Space Station</li> <li>• SR-71</li> </ul>
Saab Space	Clamp Bands	<ul style="list-style-type: none"> <li>• Ariane</li> <li>• Atlas</li> </ul>
Moore	Separation Springs	<ul style="list-style-type: none"> <li>• Atlas/Centaur</li> </ul>
Ensign Bickford Aerospace	Ordnance	<ul style="list-style-type: none"> <li>• Atlas IIAS Ignition and Destruct System</li> <li>• Titan IV Destruct System</li> <li>• Delta SRB Separation System</li> <li>• Shuttle SRB Ordnance System</li> <li>• MAXIS and Prospector</li> <li>• Pegasus and Taurus</li> </ul>

### 1679

#### H-MACS

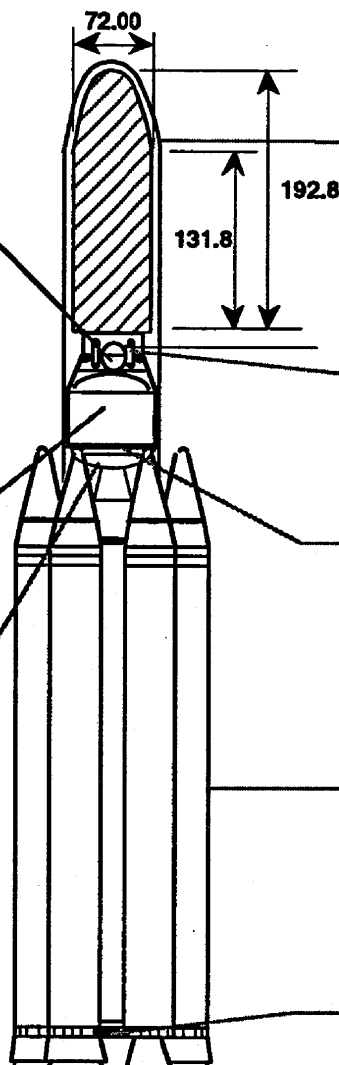
- Atlantic Research
- Every Component Has at Least 1 Flight

#### STAR 63F

- Thiokol
- 2 Flights, 100% Success

#### Interface Module

- EER
- New Design



### 1620 and 1679

#### Payload Fairing (PLF)

- TRACOR
- Extension of Conestoga 1620/COMET PLF

#### Avionics

- EER
- Repackaging of Conestoga 1620/COMET Avionics
- Flight-Proven/Qualified Components From Shuttle

#### Clamp Band

- Saab Space
- Derivative of Flight-Proven 66-Inch Atlas Band

#### CASTOR IVB (4) and CASTOR IVA (2)

- Thiokol
- Conestoga 1620/COMET Configuration
- Delta Strap-On
- CASTOR Family Has 0.999 Reliability Over 1825 Units Flown

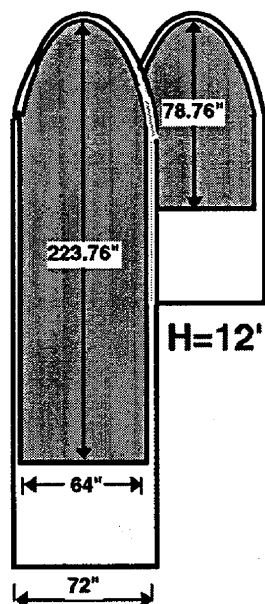
#### Core Thrust Ring/Strap-On Thrust Ring

- Mutual Tool and Die
- Conestoga 1620/COMET Configuration



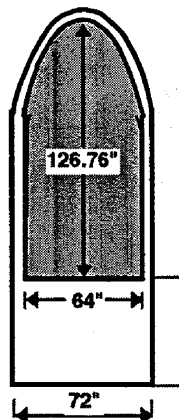
# "Vehicles of Choice"

## Payload Fairings



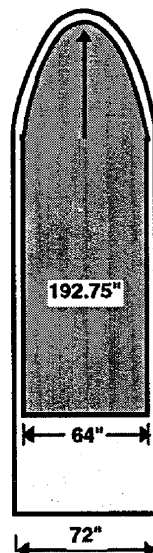
H=24'

**Conestoga  
Capability  
12' to 24'**



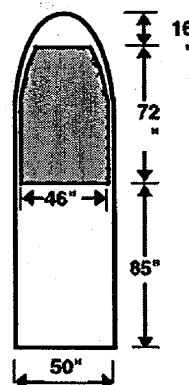
H=16'

**Conestoga  
COMET  
(Production)**



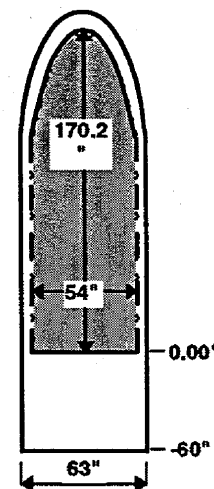
H=21.5'

**Conestoga  
OLS-2500  
(Production)**



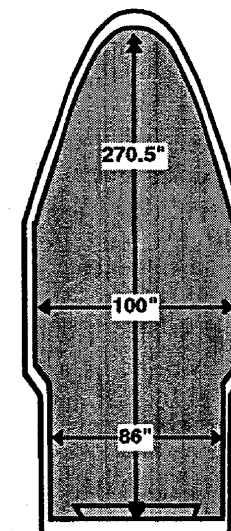
H=14.5'

**Pegasus**



H=17.5'

**Taurus**



H=22.5'

**Delta**

 Payload Dyn. Envelope

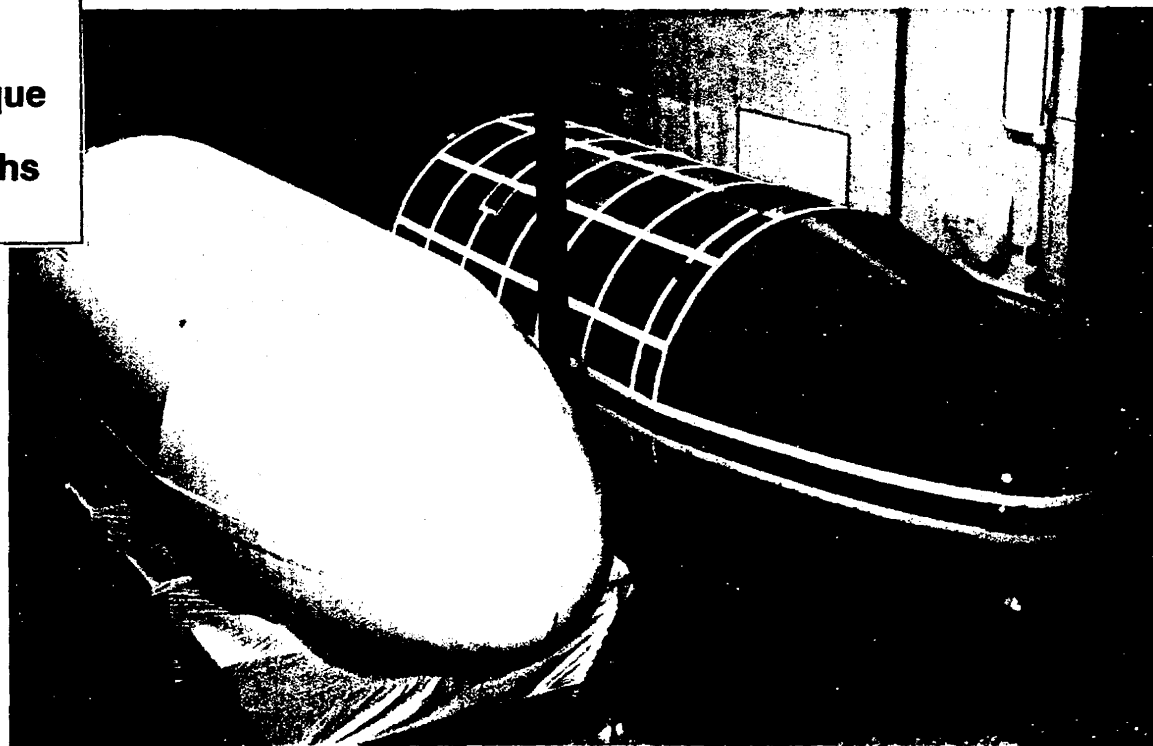
**Conestoga ELVs Offer Variable Length,  
72" Diameter Payload Fairings**

# "Vehicles of Choice"

## Conestoga Standard Diameter Fairings

### Features

- Composite Construction
- Thrusting Joint Separation System
- RF Transparent or Opaque
- 72-Inch Diameter, Lengths to 24 Feet



# "Vehicles of Choice"

## Development of Conestoga

### MILESTONES

91

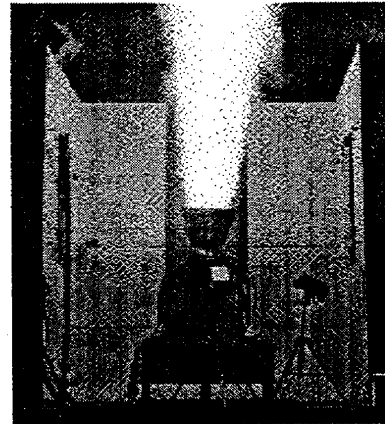
<input checked="" type="checkbox"/>	Contract Award	- 3/91
<input checked="" type="checkbox"/>	Authorization to Proceed	- 4/91
<input checked="" type="checkbox"/>	Hardware Preliminary Design Review	- 7/91
<input checked="" type="checkbox"/>	Critical Design Review	- 11/91
<input checked="" type="checkbox"/>	Flight Software Preliminary Design Review	- 11/91

92

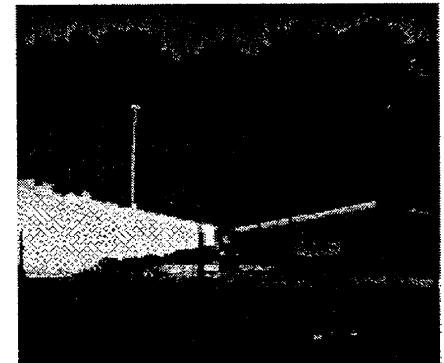
<input checked="" type="checkbox"/>	Wind Tunnel Test	- 5/92
<input checked="" type="checkbox"/>	STAR 48V Q-1 Static Test Firing	- 6/92
<input checked="" type="checkbox"/>	Flight Software Critical Design Review	- 7/92
<input checked="" type="checkbox"/>	CASTOR IV A/B SRMs, Hardware Components Complete	- 10/92
<input checked="" type="checkbox"/>	STAR 48V Flight SRM Poured	- 11/92
<input checked="" type="checkbox"/>	MAXUS Flight (CASTOR IVB)	- 11/92
<input checked="" type="checkbox"/>	Wallops Flight Facility Launch Pad Poured	- 11/92
<input checked="" type="checkbox"/>	Strap-on Thrust Ring Fabrication	- 11/92
<input checked="" type="checkbox"/>	Jettison Hardware Fabrication	- 12/92
<input checked="" type="checkbox"/>	Clamp Band Fabrication	- 12/92

93

<input checked="" type="checkbox"/>	WFF Launch Site and Service Tower Complete	- 1/93
<input checked="" type="checkbox"/>	STAR 48V Q-2 Static Test Firing	- 3/93
<input checked="" type="checkbox"/>	Payload Fairing Separation Test	- 3/93
<input checked="" type="checkbox"/>	CASTOR IV A/B SRMs Delivered to WFF	- 3/93
<input checked="" type="checkbox"/>	EGSE Fabrication	- 4/93
<input checked="" type="checkbox"/>	MGSE Fabrication	- 6/93
<input checked="" type="checkbox"/>	Certified Flight Software Delivery	- 8/93
<input checked="" type="checkbox"/>	Avionics Integration Complete	- 9/93
<input type="checkbox"/>	COMET Initial Launch	- /94



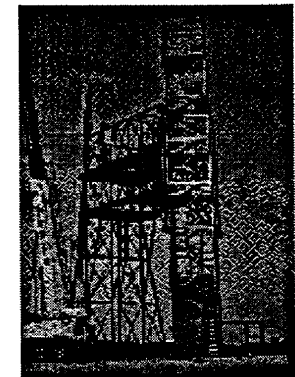
**STAR Motor**



**CASTOR Motor**



**Wallops Launch Pad**



**Portable Service Tower**

## **Qualification Testing Performed at Unit, Subsystem, and System Levels**

### **Subsystem/Component Level**

- **Static Load Test for All Load Bearing Structures**
- **Random Vibration and Thermal Cycling for All Components at the Unit Level**
- **Pyrotechnic Separation Tests**
  - **Fairing**
  - **Third Stage Clamp Band and Springs**
  - **Jettison Thrusters**
- **Ordnance**
  - **ISDS Interrupter Qualification**
  - **Subscale System Test**
- **STAR 48V Static Test Firings**

### **System Level**

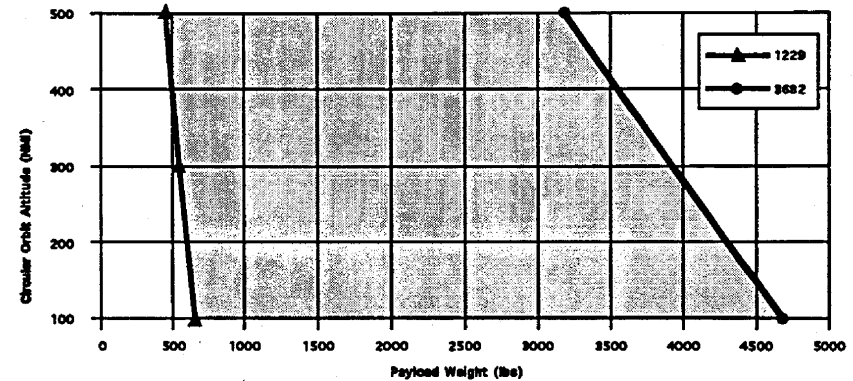
- **EMI Test for the Upper Stack Assembly**
- **Acoustic Testing of the Upper Stack Assembly**
- **Software**
  - **Hardware-in-the-Loop Test**
- **End-to-End Mission Sequence Testing on Pad**
- **Wind Tunnel Test**

# "Vehicles of Choice"

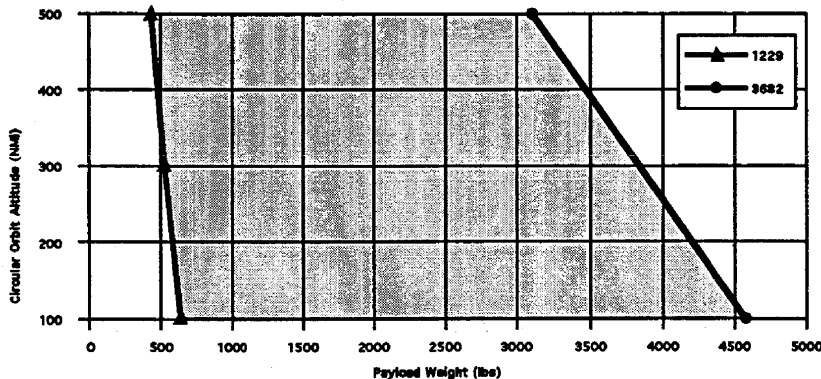
## Conestoga Performance

- Modularity of Conestoga Fleet Provides Continuous and Flexible Size Selection for a Broad Range of Payload Requirements From 500 to Over 4500 Pounds
- Allows "Right Sizing" for Most Cost-Effective Match of Vehicle and Payload
- Common Motor Families Support All Configurations
- Fairing Design and Range of Standard Lengths Offer Users a Variety of Size and Access Options

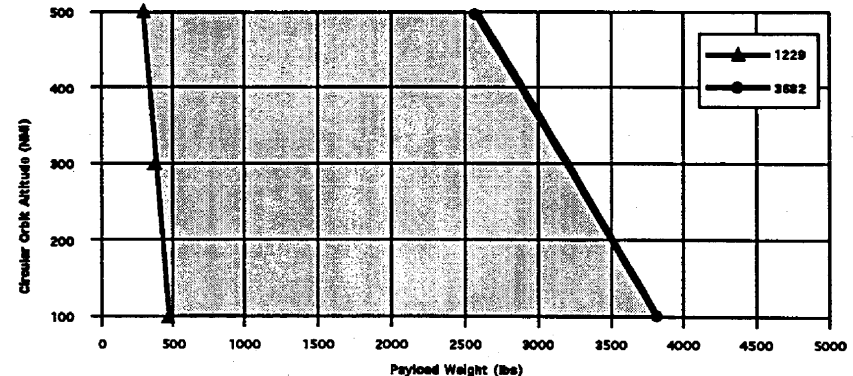
Circular Orbit – 28.5 Degree Inclination (ETR)



Circular Orbit – 38 Degree Inclination (WFF)



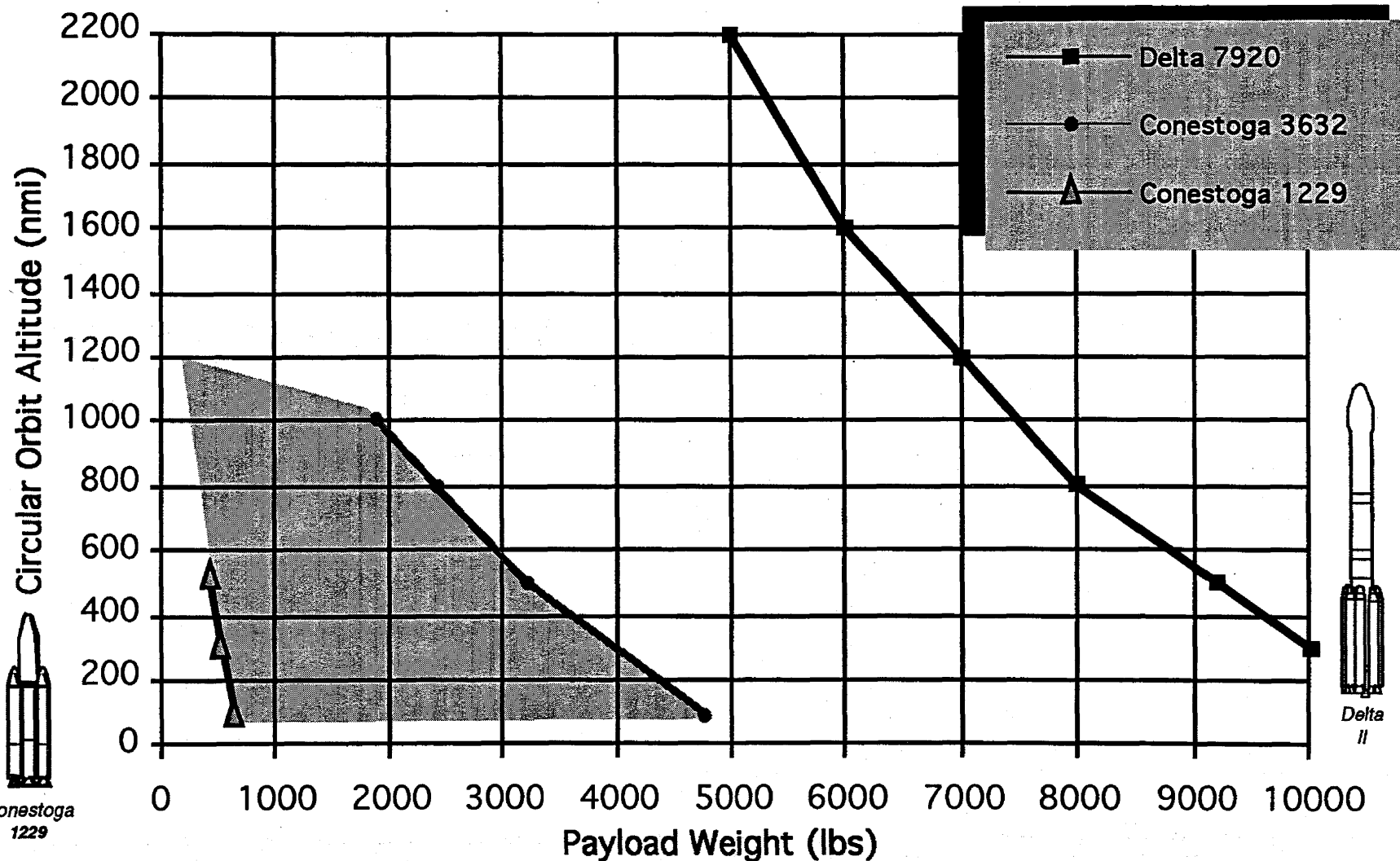
Circular Orbit – 90 Degree Inclination (WTR)



# "Vehicles of Choice"

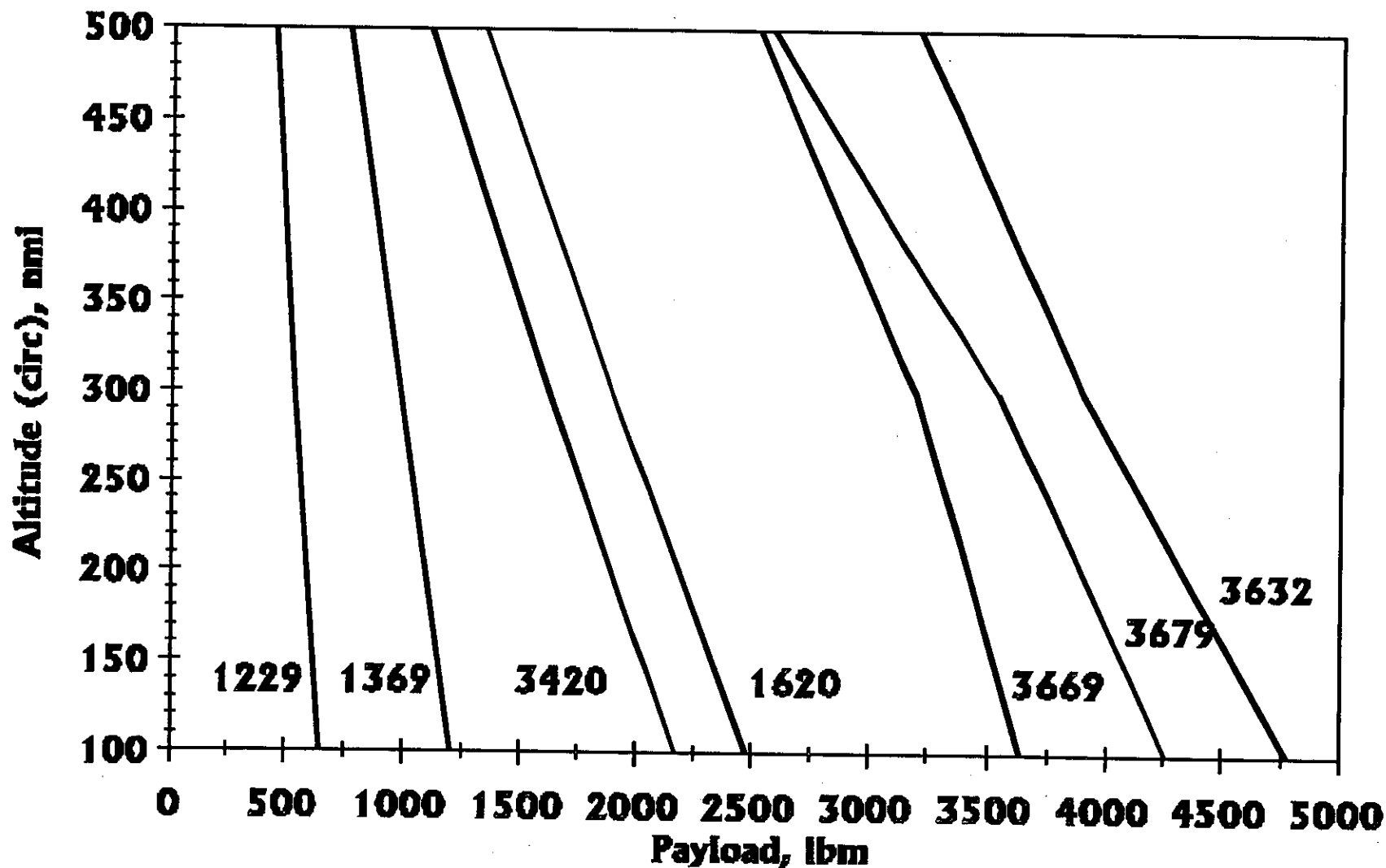
## Conestoga Modular "Niche"

Inclination - 28.5 Degree (ETR)



# "Vehicles of Choice"

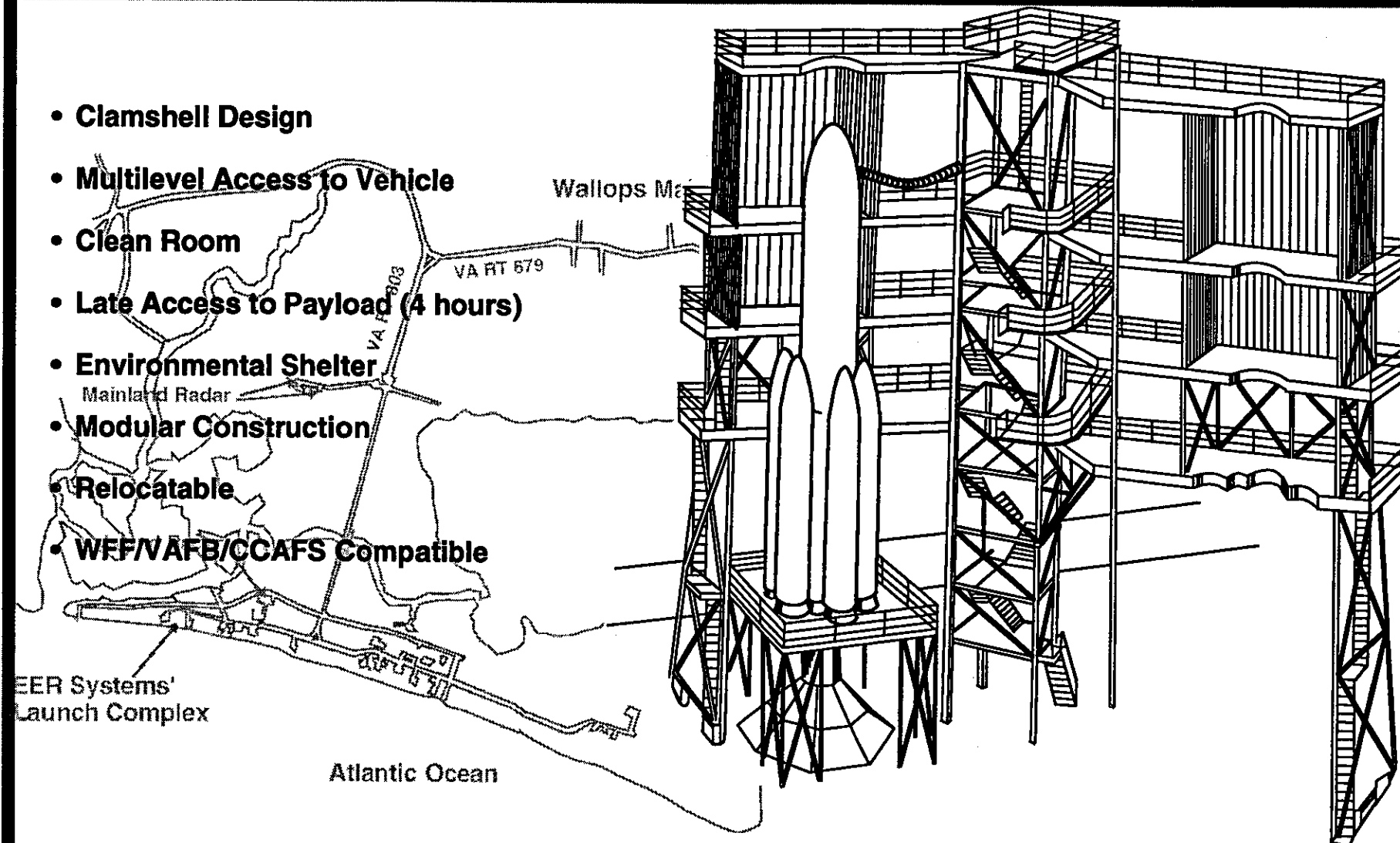
Conestoga Performance  
28.5 Degree Inclination



# "Vehicles of Choice"

## Conestoga Launch Pad

- Clamshell Design
- Multilevel Access to Vehicle
- Clean Room
- Late Access to Payload (4 hours)
- Environmental Shelter
- Modular Construction
- Relocatable
- WFF/VAFB/CCAFS Compatible



152



- **Upperstage Lift Fixture and Support Pallet**

Combined support stand and lift fixture for Upperstage buildup, transport to the Launch Pad, and installation on the Core CASTOR.

- **Tower Monorail**

One Ton hoist located in overhead area of Level 4 with pivot point of approximately 90° to position Payload units directly over the vehicle centerline for late access installation.

- **Upperstage Environment Curtain**

Provides enclosure around the Payload and Upperstage for maintaining the positive air flow and clean environment during payload integration at the pad.

- **SRM Thermal Environment Curtain**

Provides enclosure for providing/maintaining a constant predetermined temperature to optimize the SRM performance.

- **Temporary Support Structure (TSS)**

Provides temporary support to the core castor during CASTOR strap-on installation at the Launch Pad.

- **CASTOR Motor Installation GSE**

**Provides hoisting and mating capability of Core and Strap-On CASTORs to the Launch Mount. Includes the CASTOR Breakover Fixture, Aft Trunnion Pins, Forward Lifting Lugs, Forward Lifting Fixture, Horizontal Lifting Beam, Motor Chocks, Temporary Support Stand.**

- **Fairing Transfer Canister**

**Container to protect and transport the Fairing and/or Payload to the Launch Pad for installation onto the Launch Vehicle.**

- **IFM Electrical Umbilical Retraction System**

**Provides attach and retract mechanism for electrical umbilical. Initial signal sent for retraction at vehicle "first motion".**

- **Fairing ECS Umbilical Retraction System**

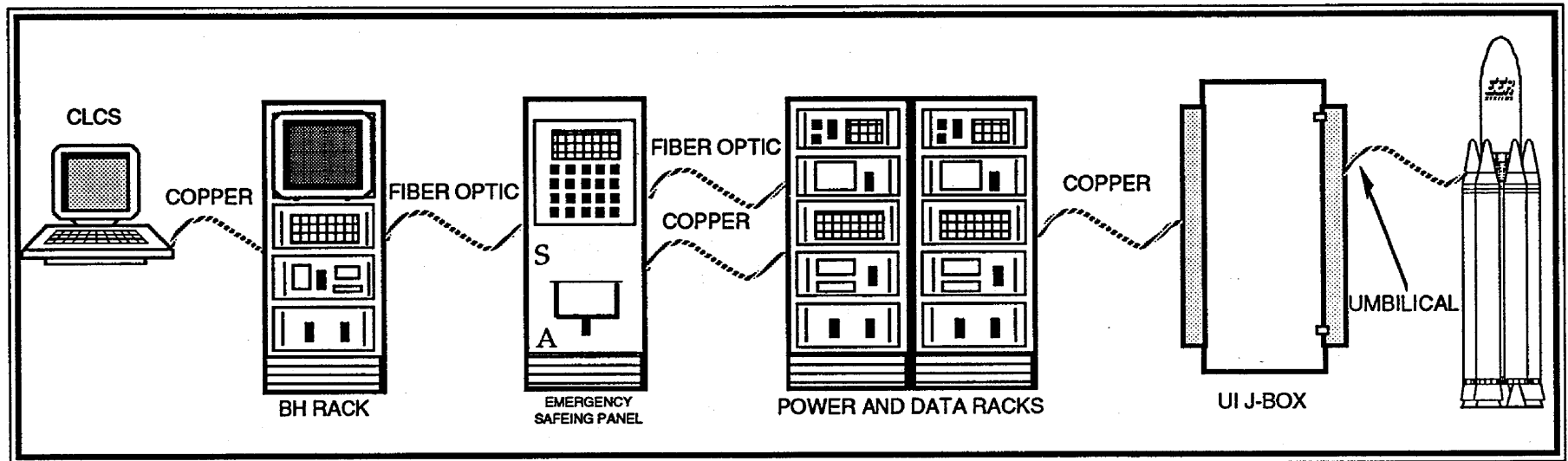
**Provides attach system for ECS ducting and retract mechanism. Initial signal sent for retraction at vehicle "first motion".**

- **Hydraulic Cart**

**Provides hydraulic source for CASTOR TVC systems testing prior to launch.**

# "Vehicles of Choice"

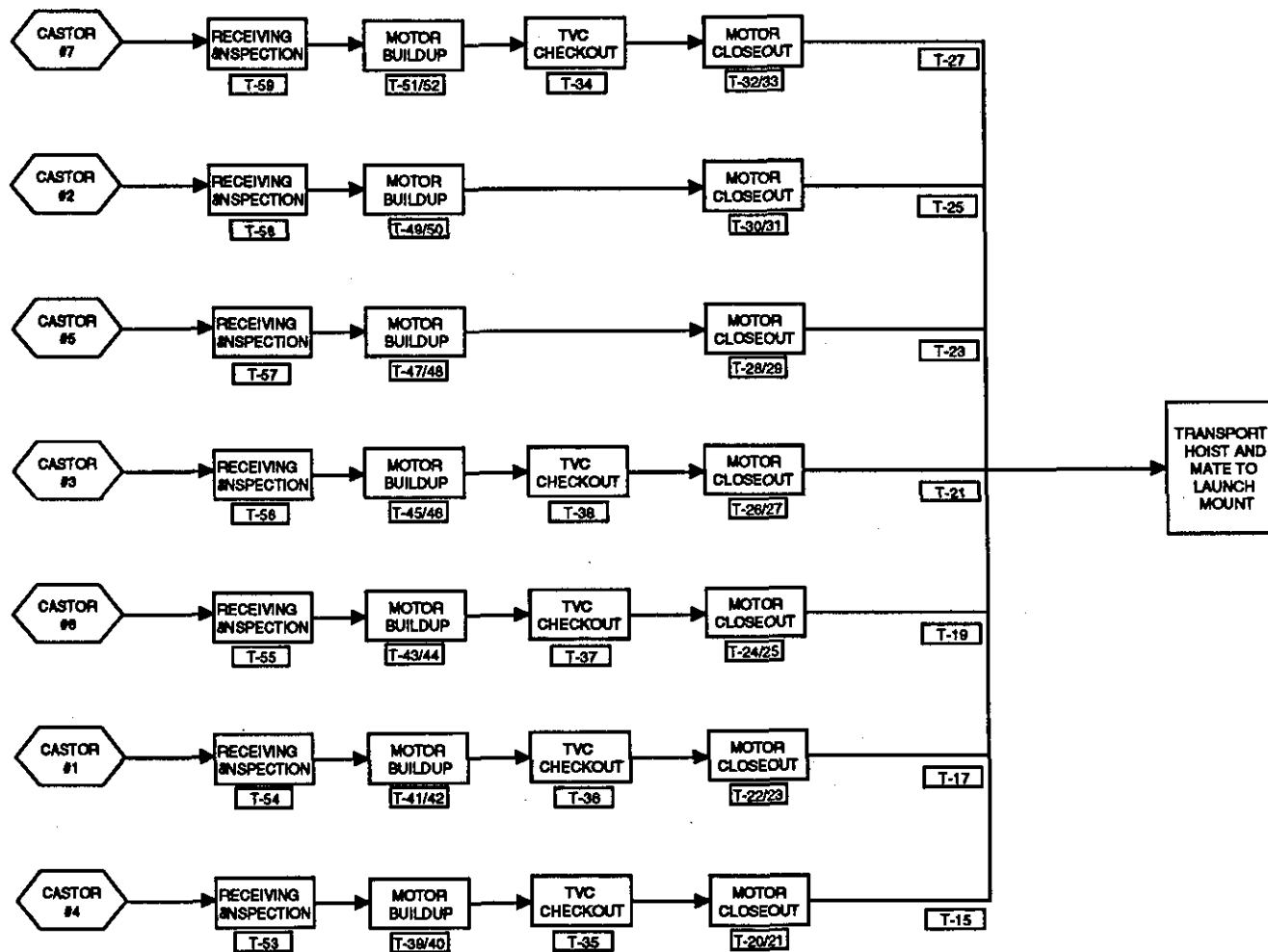
## Launch Operations Electrical Ground Support Equipment



- **Conestoga Launch Control System (CLCS)** – Controls the Launch Vehicle Subsystems via EGSE and originates all testing, countdown, and launch operations.
- **Blockhouse Rack (BH Rack)** – Provides for the conversion interface for telemetry (T/M) data to and from the Launch Vehicle and contains the ground telemetry unit for decommutating T/M data.
- **Emergency Safing Panel** – Provides the independent and remote mechanical mechanism to disable and/or safe the Launch Vehicle Safe and Arm (S&A) devices and all of the Electro-Explosive Devices (EEDs) of the Launch Vehicle.
- **Power and Data Racks** – Provides ground power for the Launch Vehicle, S-Band Receiver, and Bit Synchronizer.
- **Umbilical Interface Junction Box (UI J-Box)** – Provides the interface between the Launch Vehicle (LV) and the EGSE via the umbilical and provides the electrical and power signal interface to the LV and external EGSE circuitry.
- **Ordnance Simulator** – Provides simulation of the actual LV ordnance devices such as EEDs and S&As during flight simulation.
- **Launch Vehicle Simulator** – Provides simulation of the LV during the flight simulation and also for Pad certification.

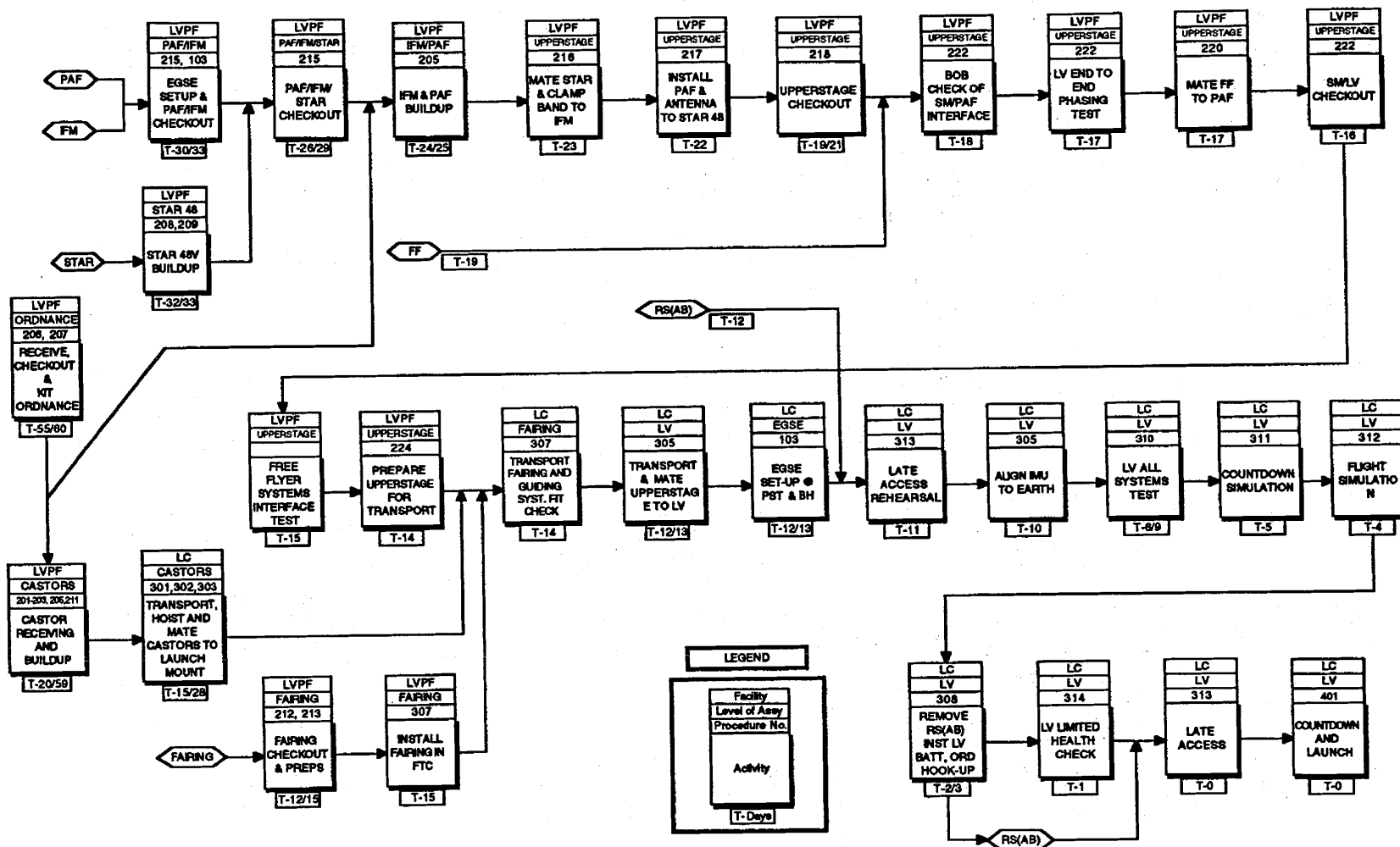
# "Vehicles of Choice"

## Assembly, Integration and Test Flow



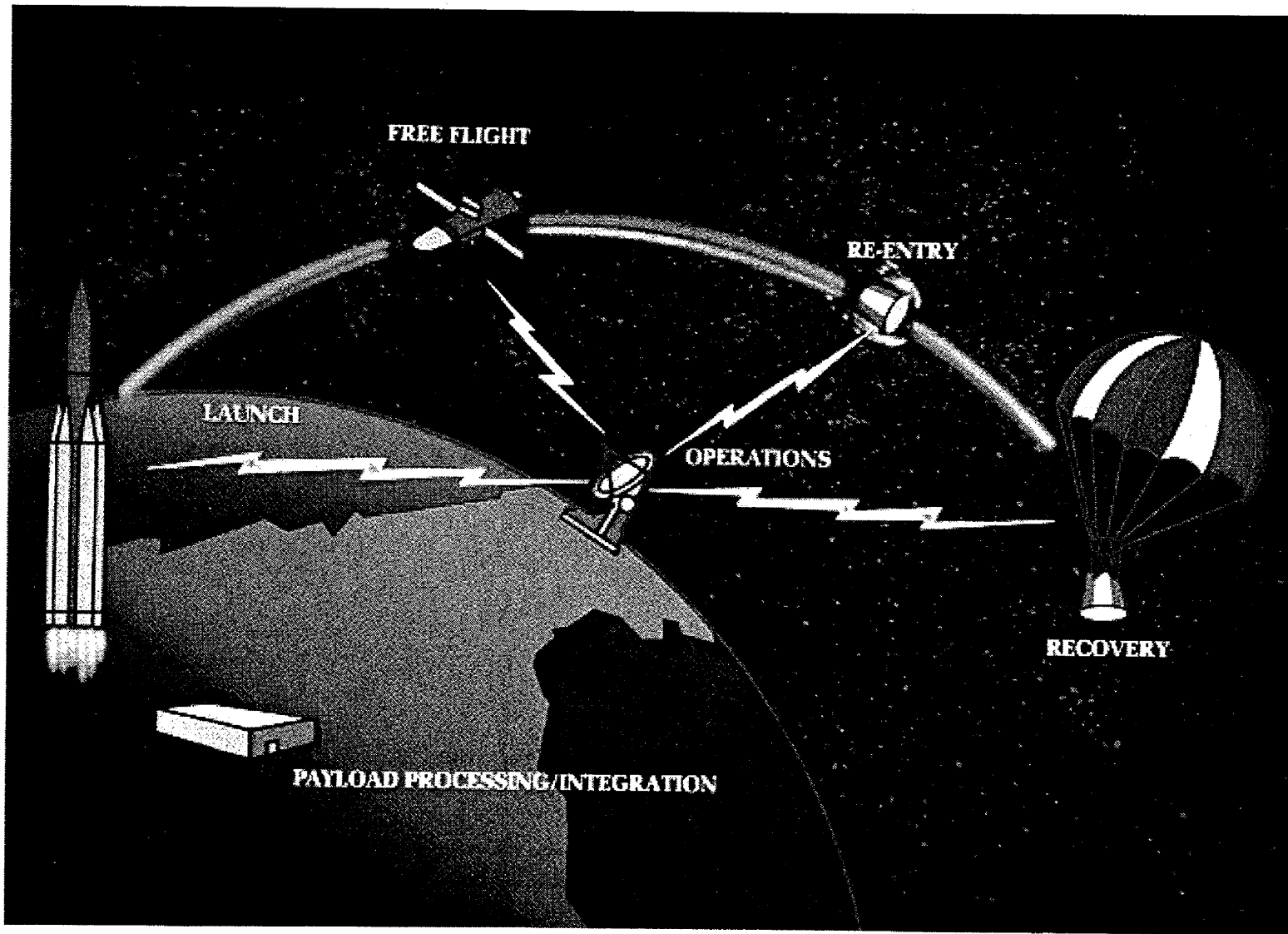
# "Vehicles of Choice"

## Assembly, Integration and Test Flow

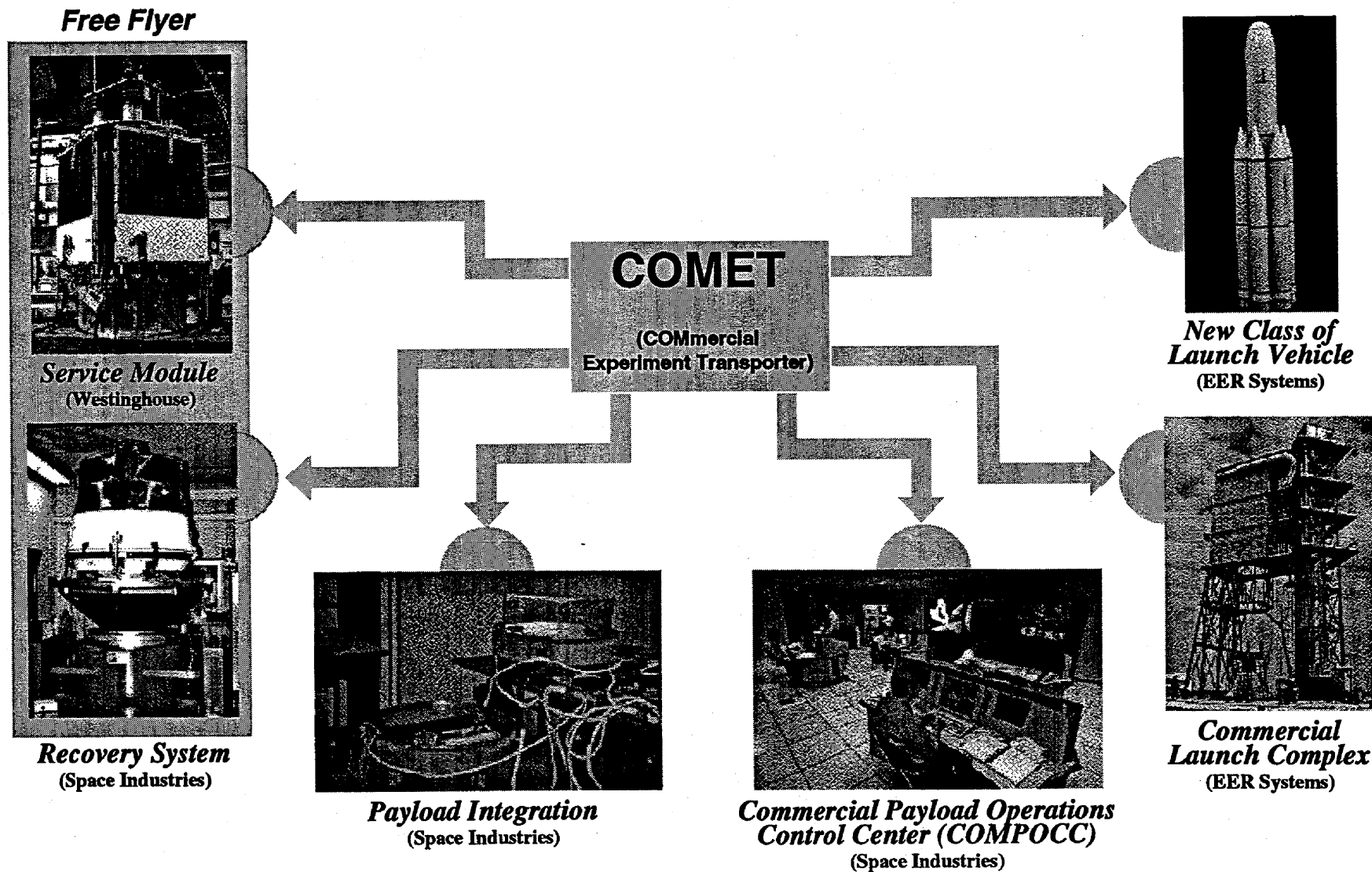


# "Vehicles of Choice"

## COMET Program Concept



# Mini Space Transportation System



# "Vehicles of Choice"

## COMET Program Elements

<u>Program Element</u>	<u>Contractor</u>	<u>CCDS* Monitor</u>
COMET Program		Center for Space Transportation and Applied Research (CSTAR)
Systems Engineering	Westinghouse	CSTAR
Payload Integration	Space Industries	Center for Macromolecular Cystollagraph
Launch Vehicle & Services	EER Systems	Consortium for Materials Development in Space (University of Alabama)
Service Module	Westinghouse	Center for Space Power (Texas A&M University)
Recovery Systems Services	Space Industries	BioServe (University of Colorado)
Orbital Operations	Space Industries	Space Vacuum Epitaxy Center (University of Houston)

Scheduled Launch Dates: COMET 1 1994

COMET 2 November 1994

COMET 3 September 1995

COMET 4 September 1996

COMET 5 September 1997

Under Review

\* Center for Commercial Development of Space



# "Vehicles of Choice"

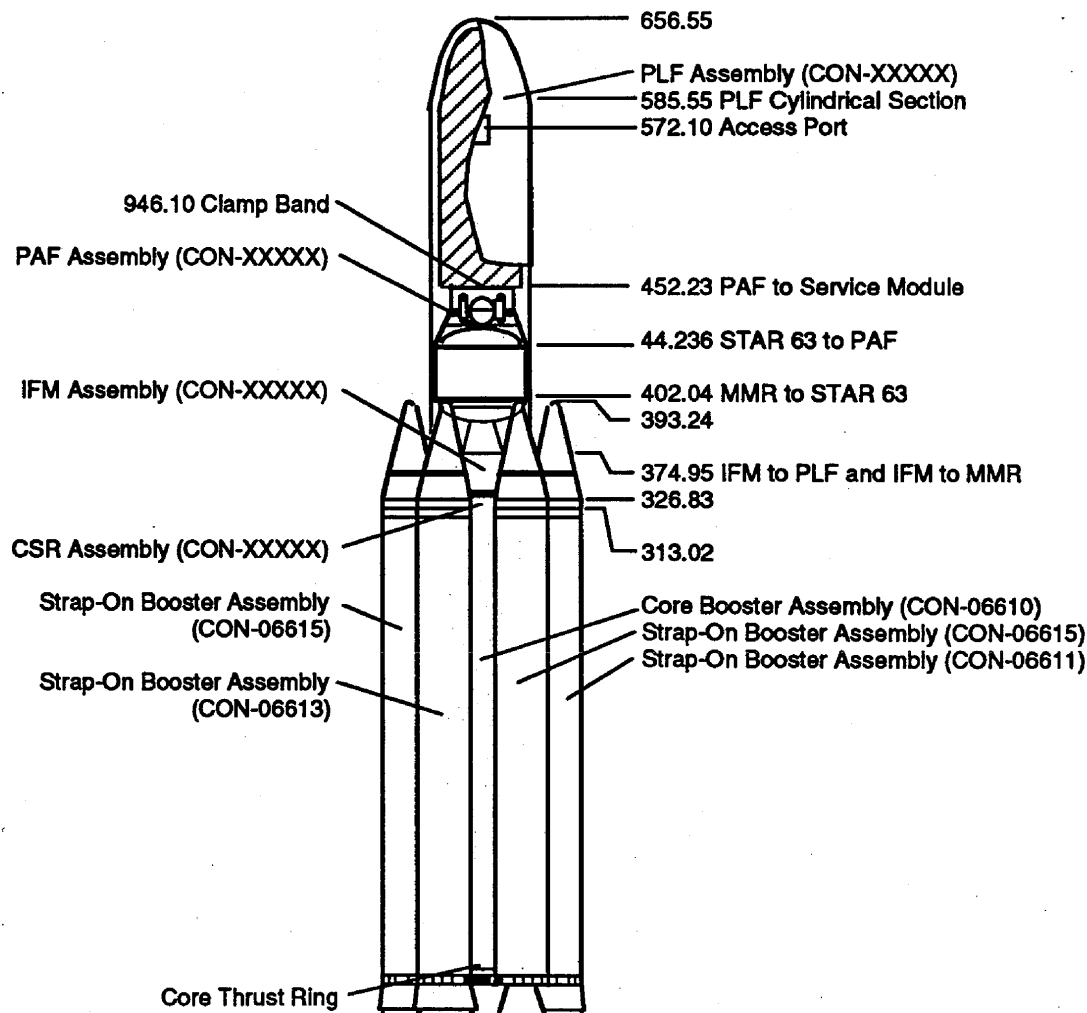
## MSTI-5 Launch Vehicle

- **Launch Vehicle Required Performance**

- 3000 lb Payload Into 125 x 125 nm Orbit
- Any Inclination Acceptable
  - Tolerance of  $\pm 2^\circ$  on Selected Versus Achieved Inclination

- **Conestoga 1679 Launch Vehicle Performance**

- 3000 lb Into 125 x 125,  $\pm 10$  nm Orbit
- $38 \pm 0.5^\circ$  Inclination



Fiscal Year	1992				1993				1994				1995				1996				1997				1998			
Calendar Year	1992				1993				1994				1995				1996				1997				1998			
Quarter	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
<b>COMET</b>																												
Firm Launches																												
COMET-1																												
COMET-2																												
COMET-3																												
Optional Launches																												
COMET-4																												
COMET-5																												
<b>OLS 2500</b>																												
Firm Launch																												
MSTI-5																												
Optional Launches																												
OLS 2500-1																												
OLS 2500-2																												
OLS 2500-3																												
OLS 2500-4																												

▲ Under Review

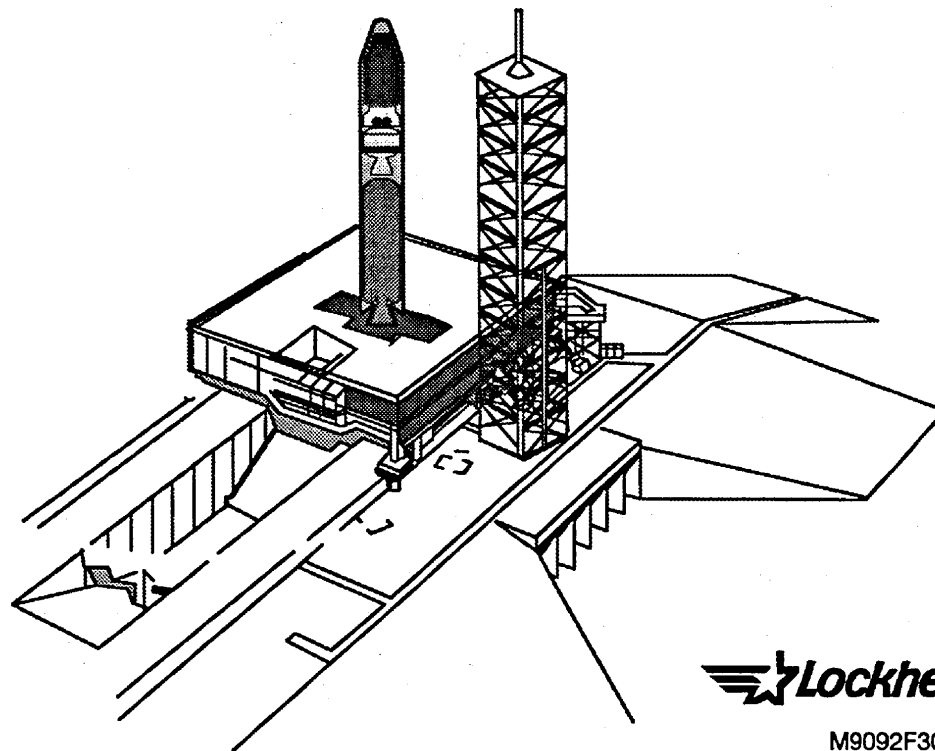
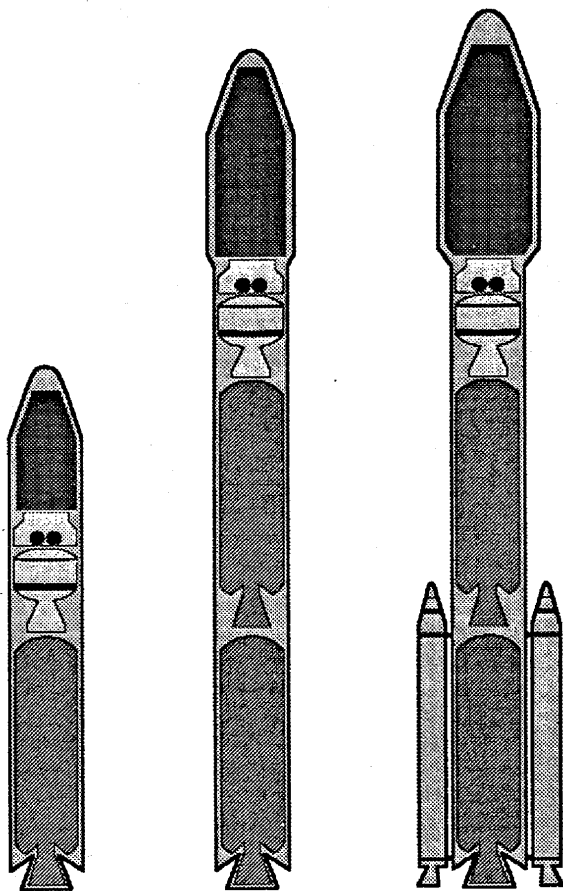
- Extensive Heritage of Flight Proven Systems and Components Provides for High Probability of Success
- Modular Design Provides Launch Vehicle Tailored to Varied Mission Requirements
- Largest Fairing in Small Launch Vehicle Arena Available in Three Standard Sizes or Custom Lengths
- Wallops Launch Facility With Portable Service Tower (PST) Is Complete – Procedures, Equipment, and PST Readily Transferable to Eastern or Western Launch Sites
- COMET and SDIO OLS2500 Vehicle Development and Mission Operations Experience Will Demonstrate/Validate Modular Components/Systems and Operational Procedures



**MSD**

# *Lockheed Launch Vehicles*

## *Introduction*



 **Lockheed**

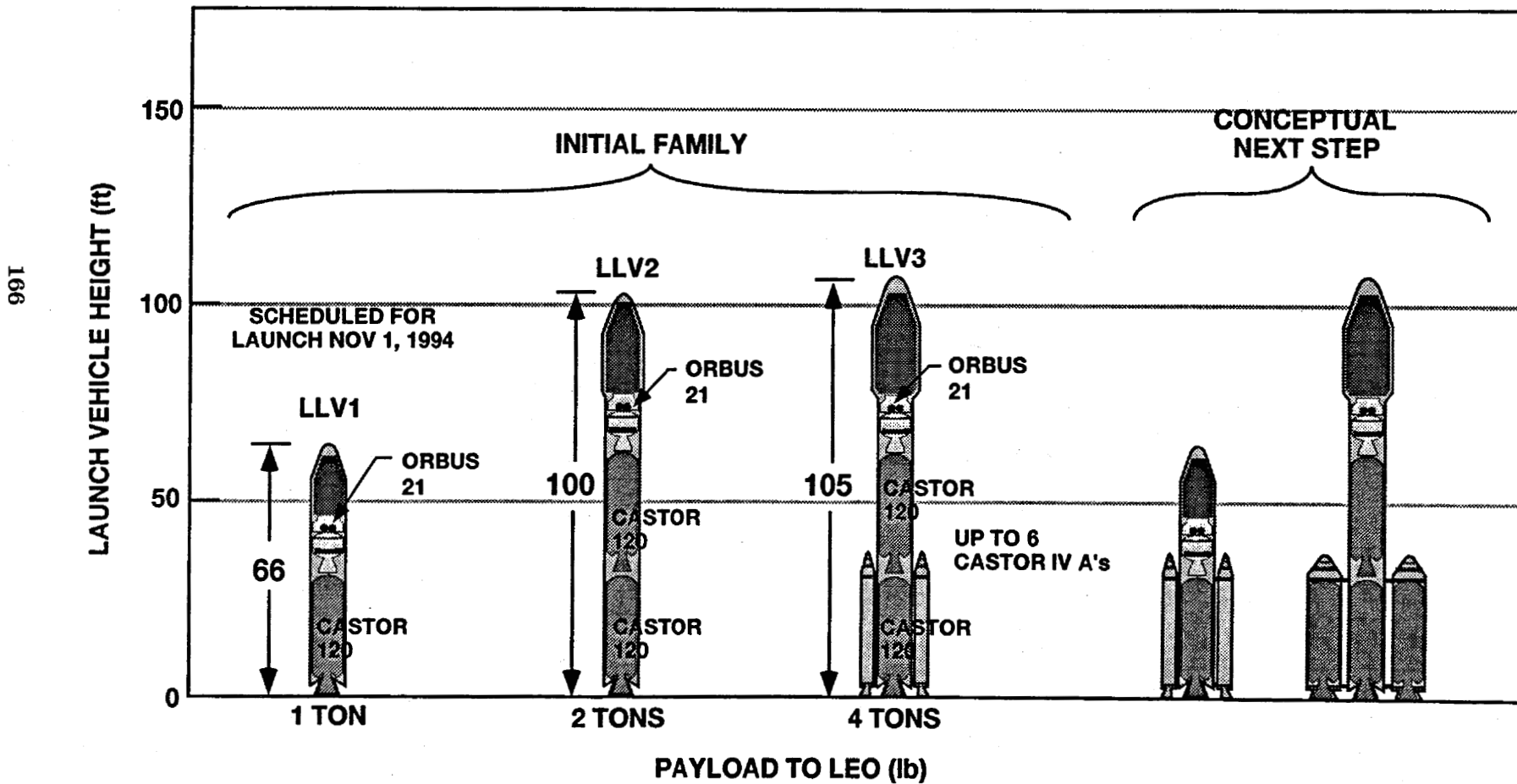
M9092F3001 3



# LOCKHEED LAUNCH VEHICLE (LLV) FAMILY



**VEHICLES HAVE COMMON AVIONICS AND ACS SYSTEMS**





## LLV DEVELOPMENT PLAN



- INITIAL PROGRAM FOCUS ON LLV1
- DEMONSTRATION VEHICLE LAUNCH 1 NOVEMBER 1994
  - 92-in. FAIRING
  - EXISTING OFFLOADED ORBUS 21
- DEVELOP LLV2/LLV3 AND LARGER FAIRING IN 1994-1995  
OR IN RESPONSE TO CUSTOMER NEED
- ADD EASTERN RANGE CAPABILITY IN 1995

### TWO-PIECE CLAMSHELL FAIRING

- ALUMINUM
- ZIP-TUBE SEPARATION JOINTS

### FAIRING SEPARATION PLANE

### SECOND STAGE SEPARATION PLANE

### FIRST STAGE SEPARATION PLANE

### ALUMINUM INTERSTAGE

### CASTOR 120™

- COMPOSITE CASE
- CLASS 1.3 HTBP PROPELLANT
- BLOWDOWN COLD GAS-POWERED HYDRAULIC TVC ACTUATORS

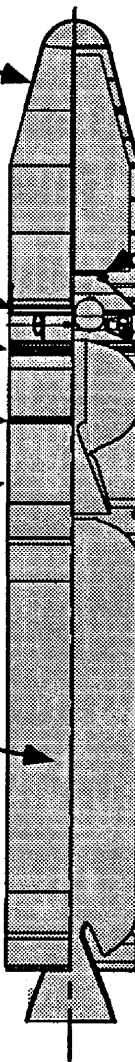
### PAYLOAD SEPARATION PLANE

### ORBIT ADJUST MODULE (EQUIPMENT SECTION)

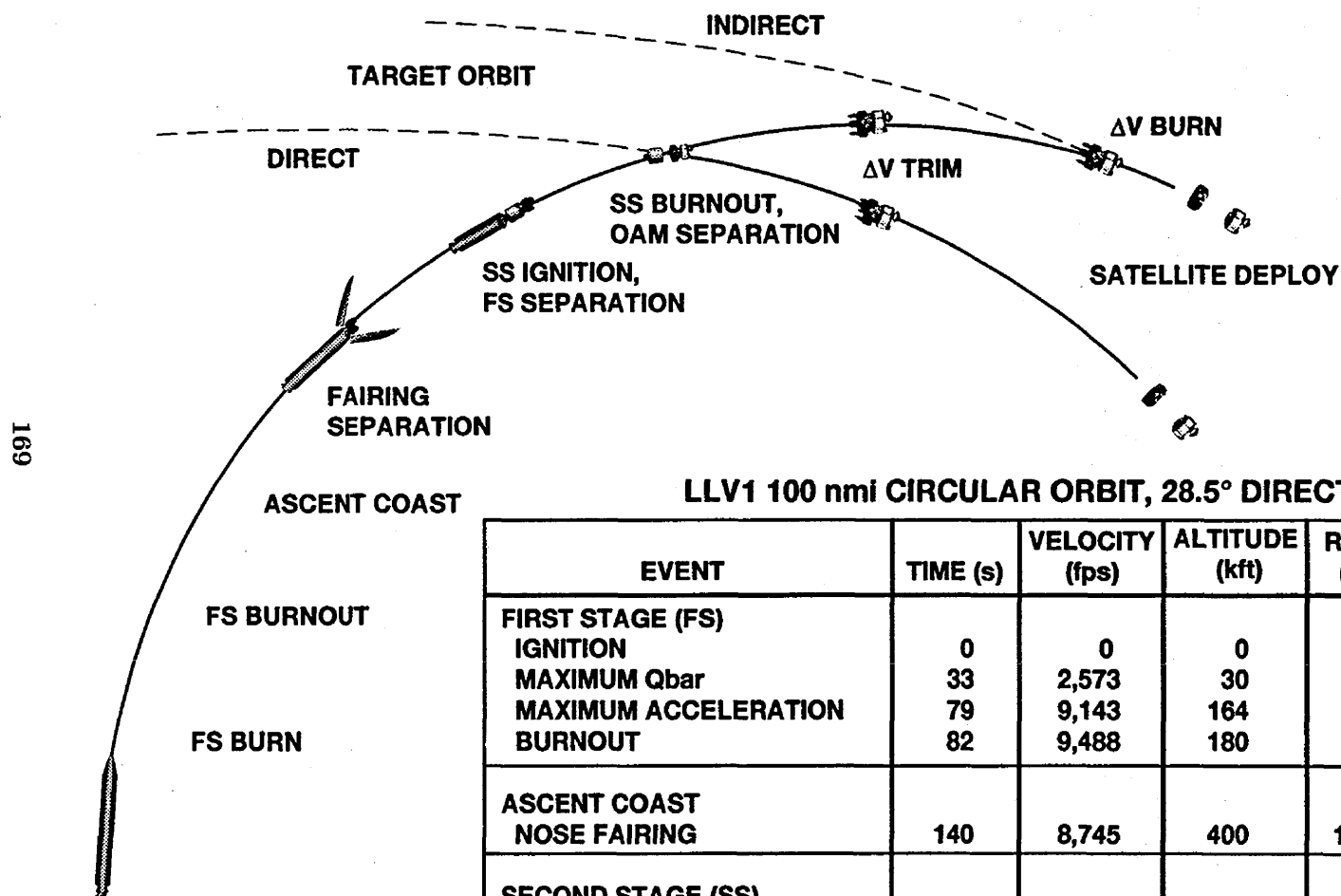
- AVIONICS
- ACS (MONOPROPELLANT)
  - 4 AXIAL THRUSTERS
  - 6 RADIAL THRUSTERS
- BATTERIES

### ORBUS 21D®

- COMPOSITE CASE
- CLASS 1.3 HTBP PROPELLANT GRAIN
- CARBON PHENOLIC NOZZLE
- ELECTROMAGNETIC TVC ACTUATORS

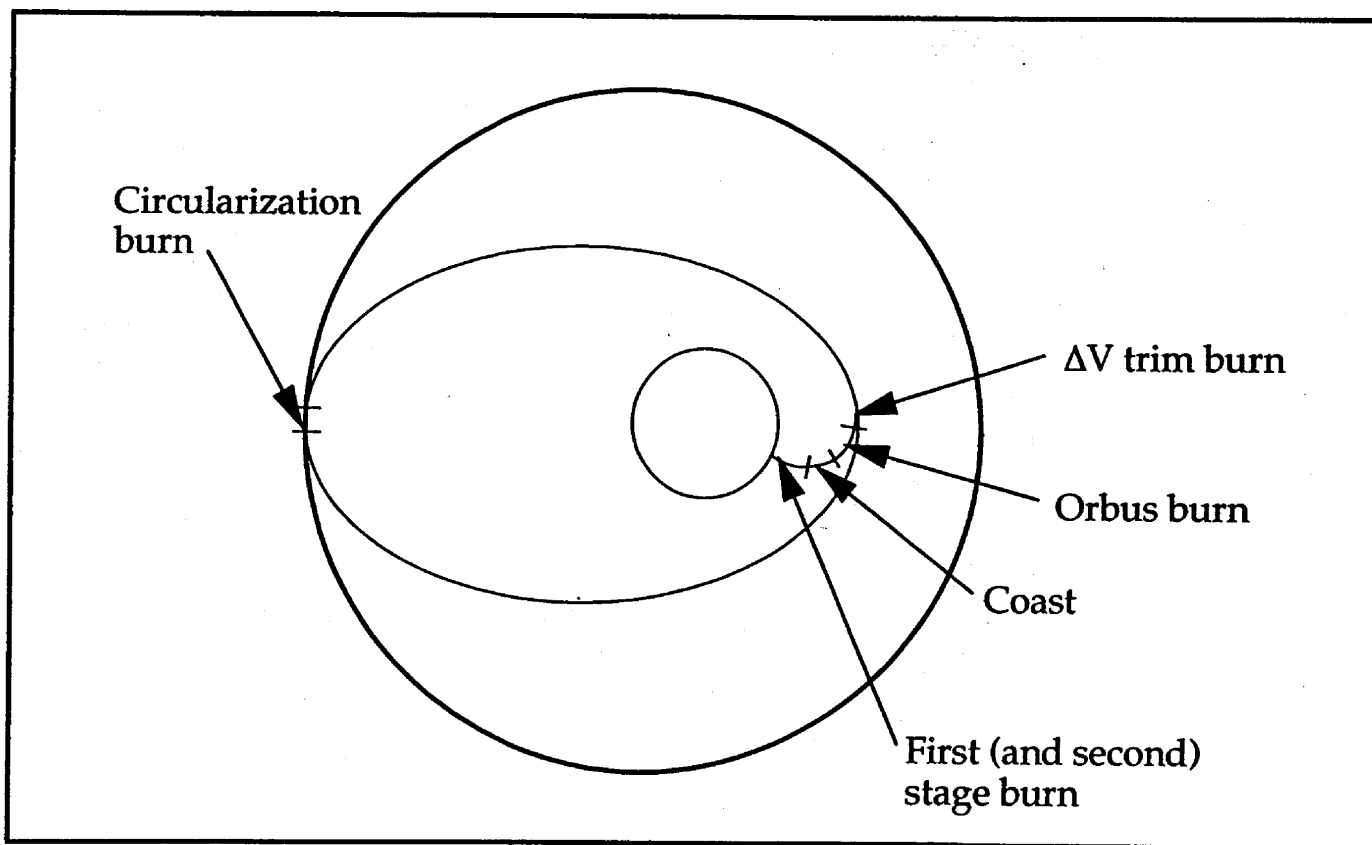






LLV1 100 nmi CIRCULAR ORBIT, 28.5° DIRECT INJECTION

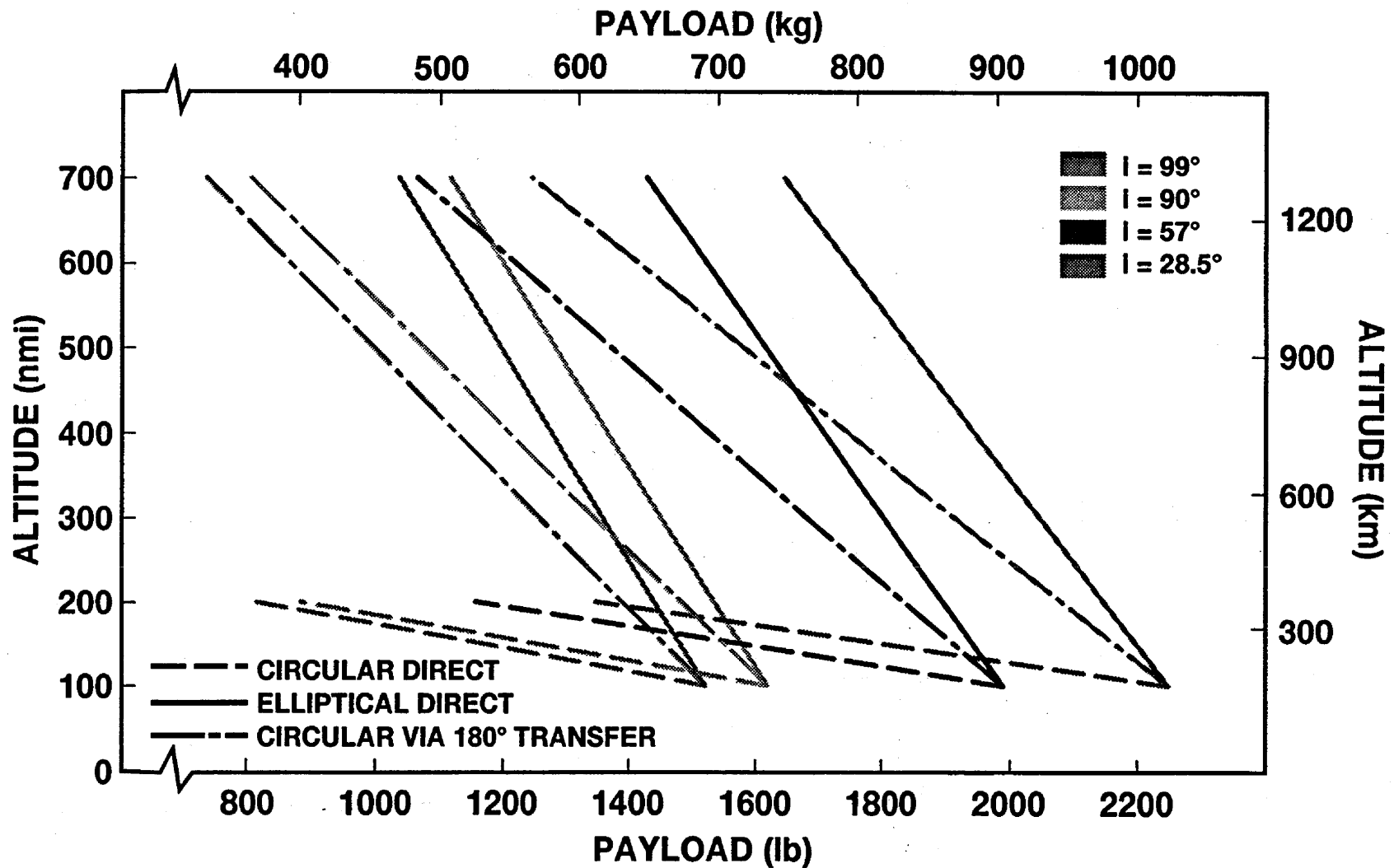
EVENT	TIME (s)	VELOCITY (fps)	ALTITUDE (kft)	RANGE (nmi)	Qbar (psf)	AXIAL ACC (g's)
<b>FIRST STAGE (FS)</b>						
IGNITION	0	0	0	0	0	0
MAXIMUM Qbar	33	2,573	30	3.8	2,950	3.3
MAXIMUM ACCELERATION	79	9,143	164	37.0	85	6.9
BURNOUT	82	9,488	180	42.0	42	0
<b>ASCENT COAST</b>						
NOSE FAIRING	140	8,745	400	123.0	0	0
<b>SECOND STAGE (SS)</b>						
IGNITION	158	8,561	445	143.0	0	0
MAXIMUM ACCELERATION	278	20,314	606	381.0	0	6.1
BURNOUT	304	24,204	608	475.0	0	0

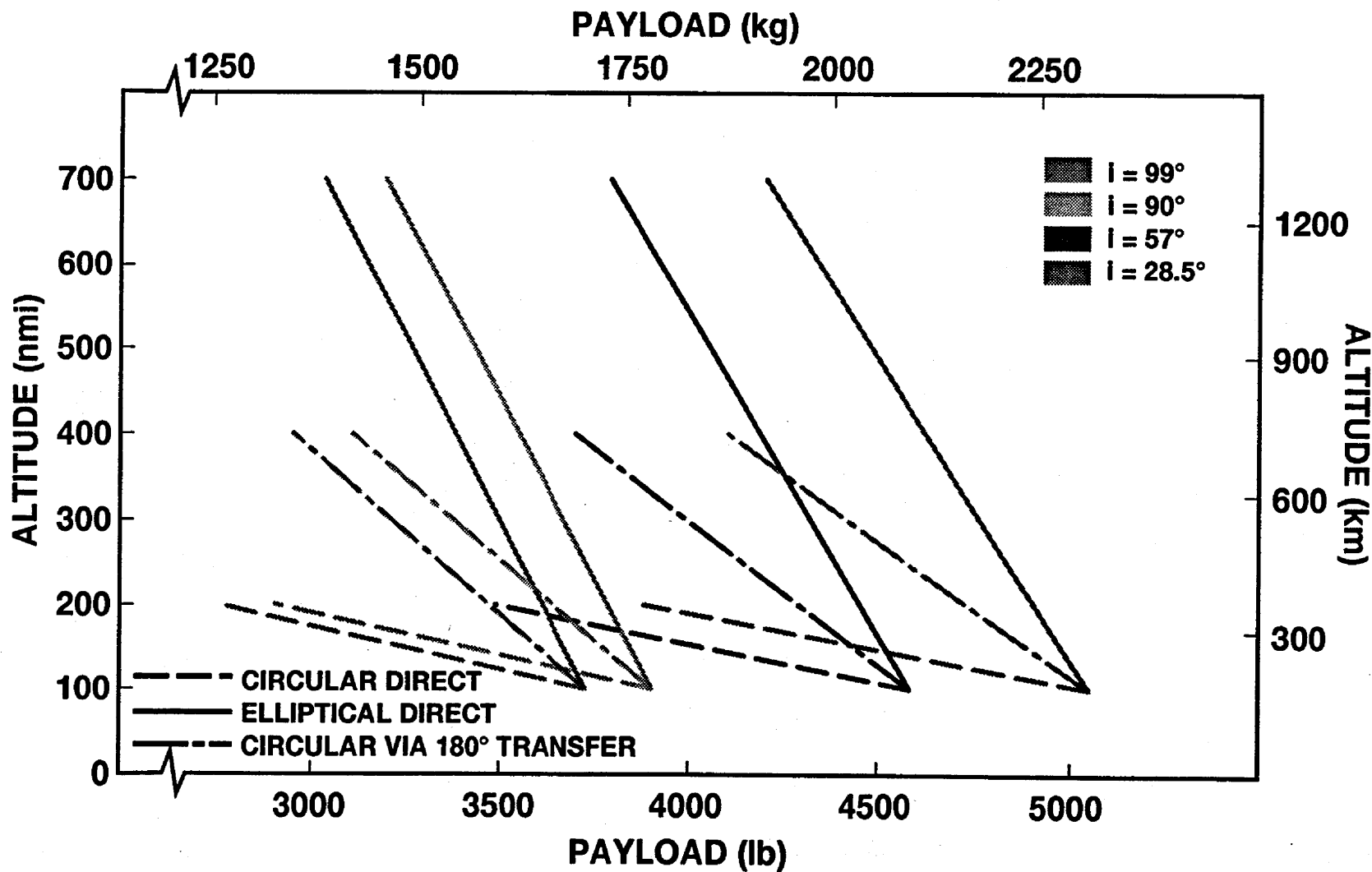


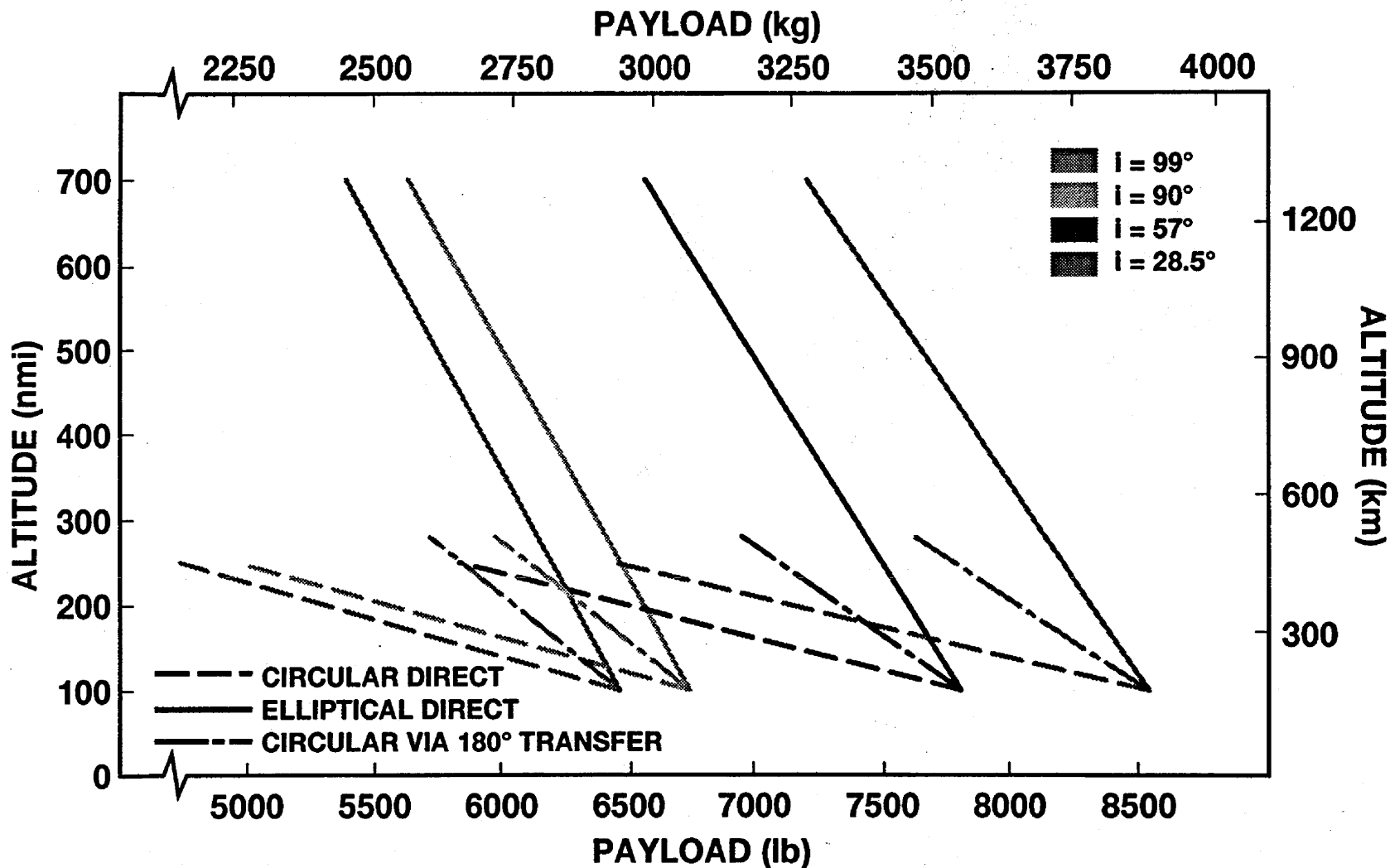
170



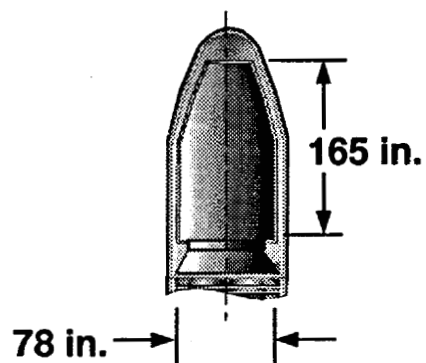
# LLV1 PERFORMANCE



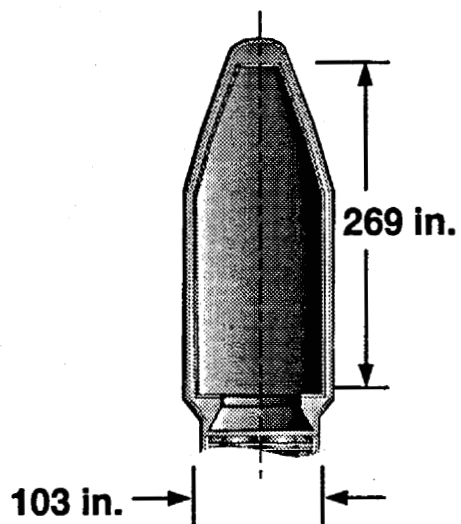




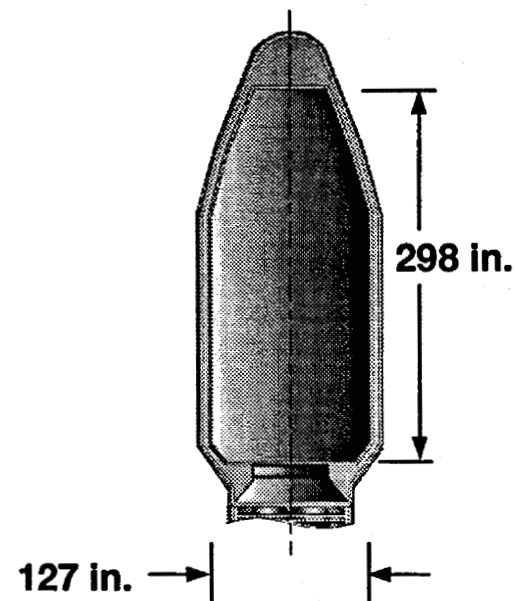
**92-in. FAIRING**

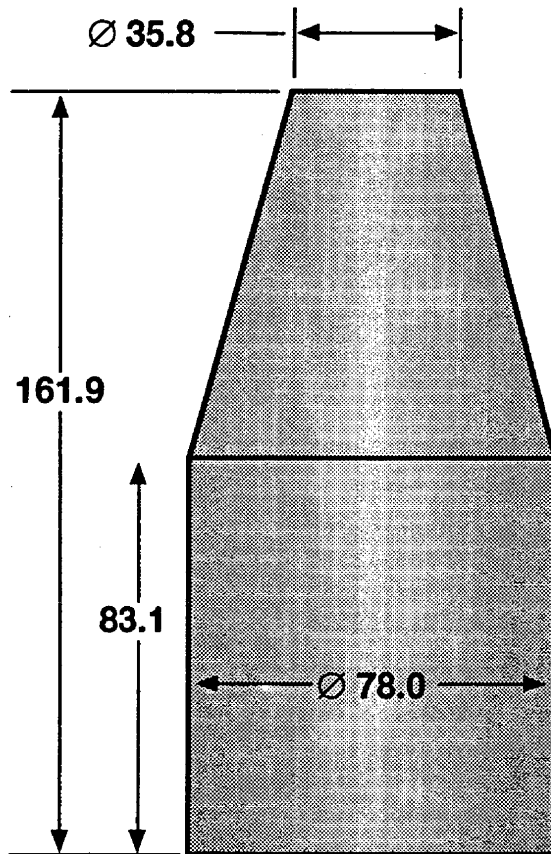


**116-in. FAIRING**

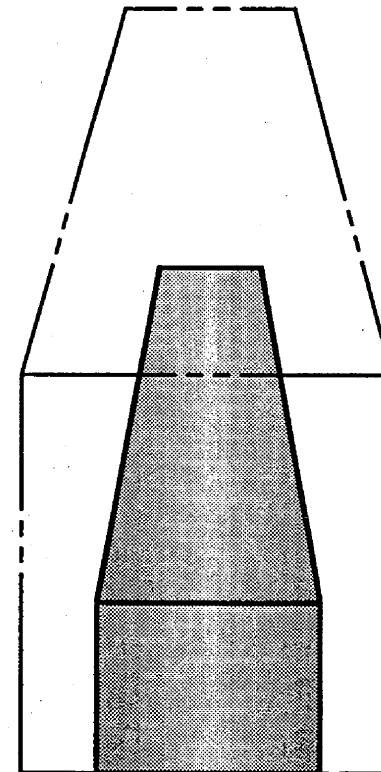


**141-in. FAIRING**





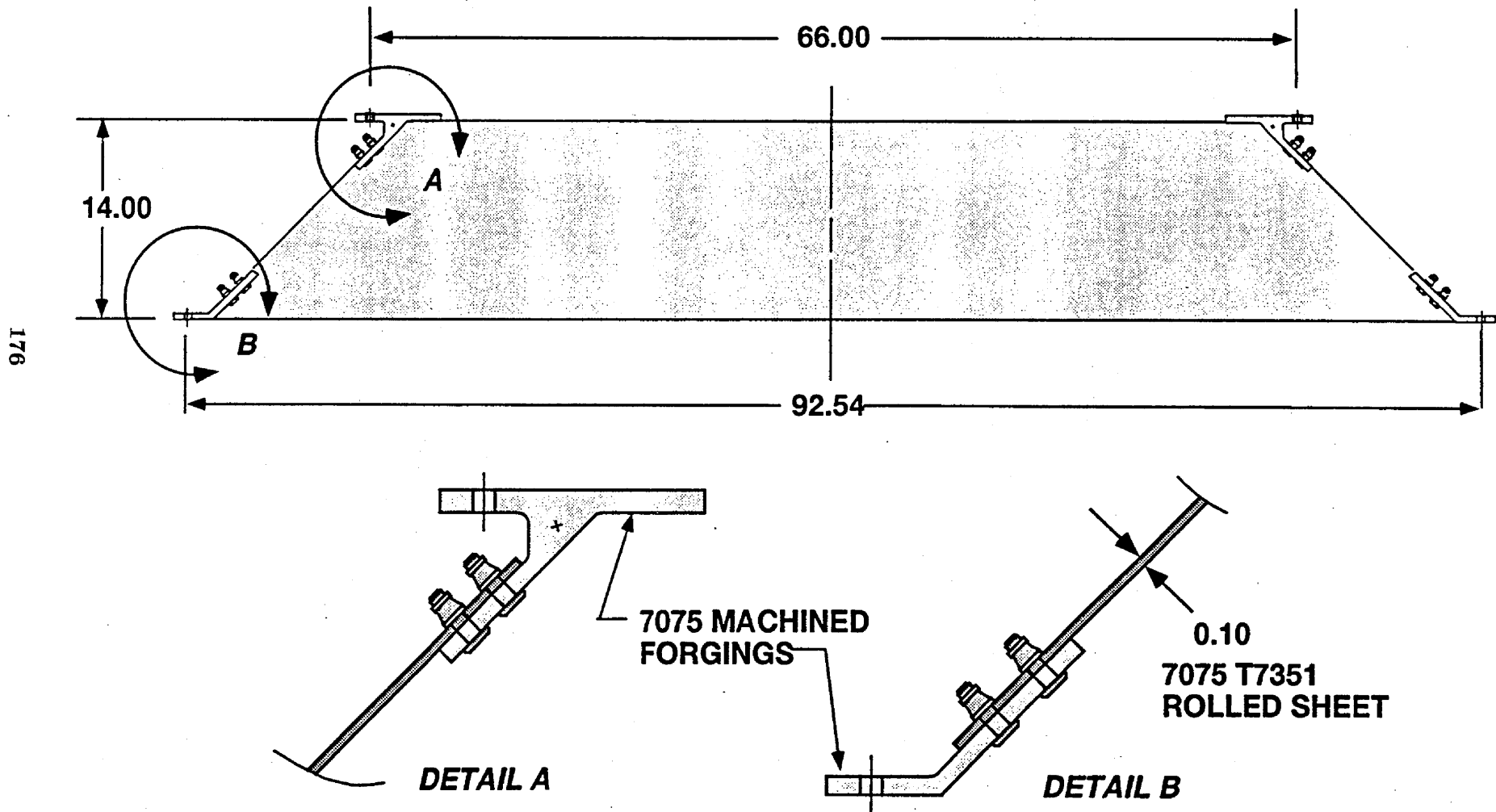
**DYNAMIC ENVELOPE**



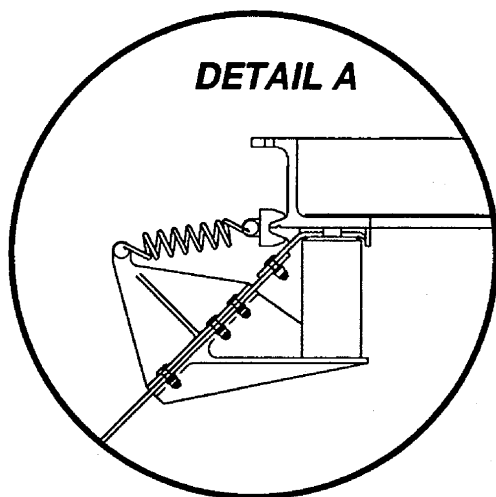
**TYPICAL SMALL PAYLOAD**



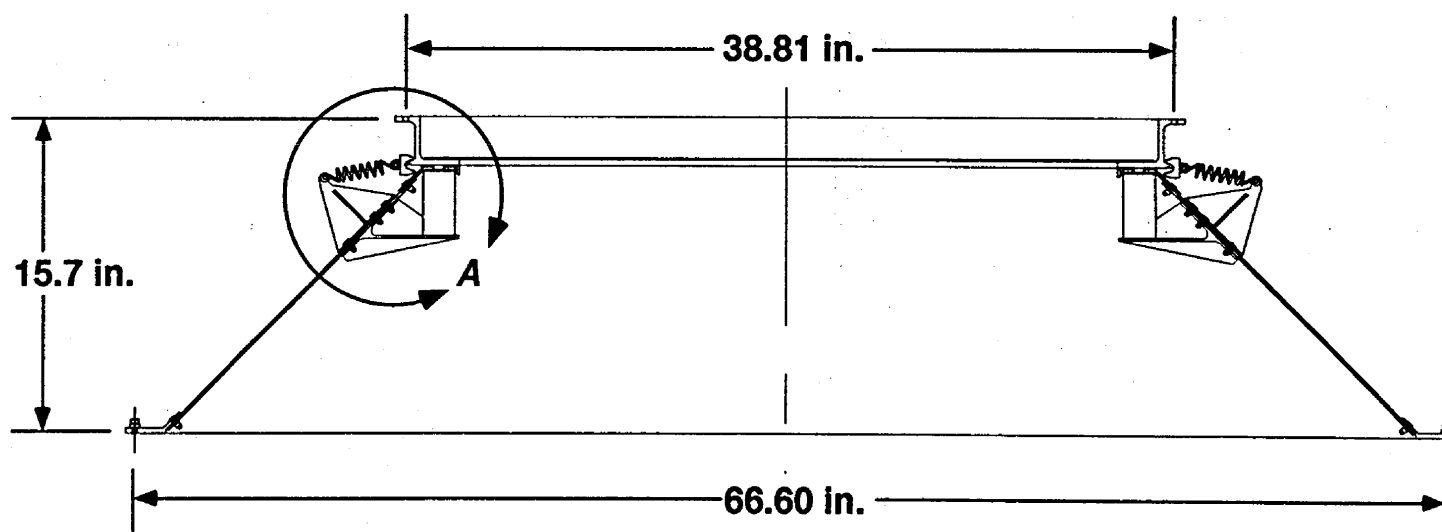
# FIXED ADAPTOR SECTION



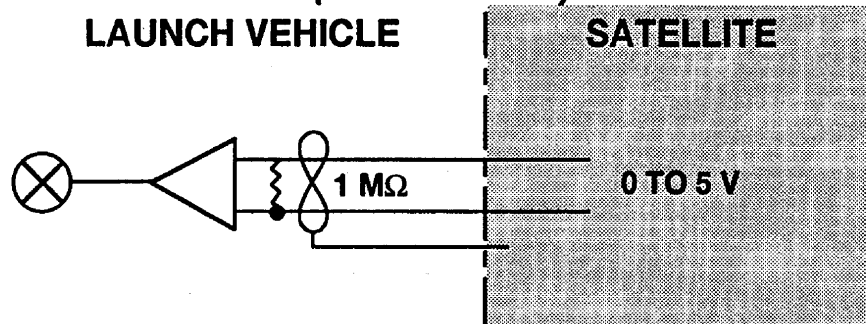




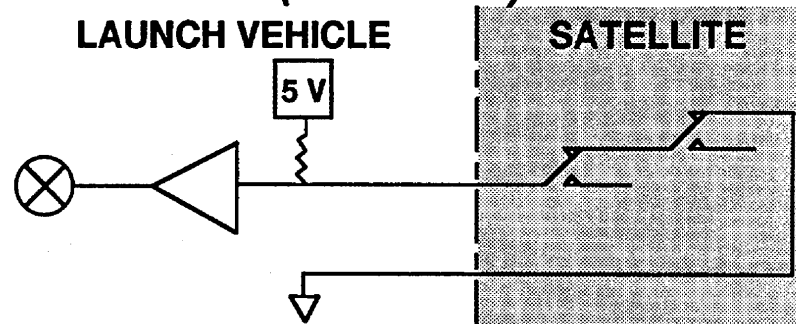
- MARMON CLAMP BAND SEPARATES AT TWO LOCATIONS
- SPRINGS RETRACT MARMON CLAMP HALVES
- SEPARATION SPRINGS (FOUR PLACES)
- PAYLOAD ADAPTOR RING (12 lb) NOT CHARGED TO PAYLOAD



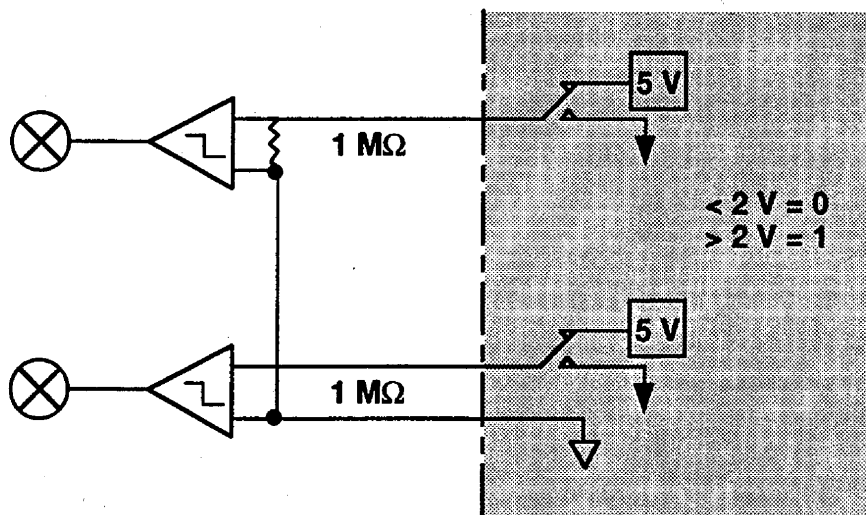
### ANALOG TELEMETRY MONITORS (10 PROVIDED)



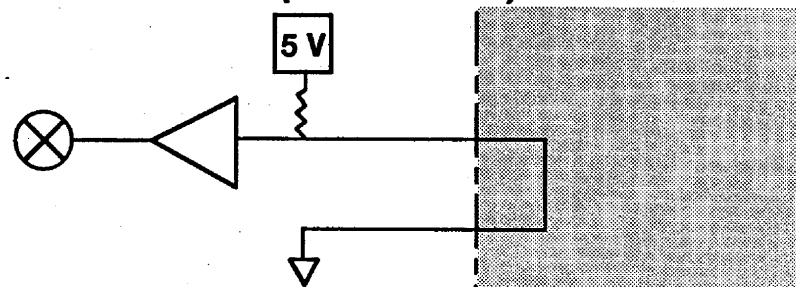
### CONTINUITY LOOPS (5 PROVIDED)



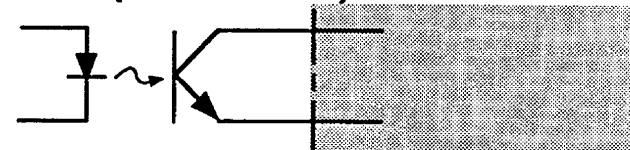
### DISCRETE TELEMETRY MONITORS (10 PROVIDED)



### SEPARATION INDICATOR (5 PROVIDED)



### COMMANDS (8 PROVIDED)



COMMAND ISSUED PER CUSTOMER-SPECIFIED CRITERIA



## PAYLOAD INTERFACE DESIGN LIMIT LOAD FACTORS



DIRECTION	LLV1	LLV2	LLV3
AXIAL <sup>(1)</sup>	+4.0 g	+1.0 g	+2.0 g
	-8.0 g	-7.0 g	-5.0 g
LATERAL <sup>(2)</sup>	+2.5 g	+2.0 g	+2.0 g
	-2.5 g	-2.0 g	-2.0 g

1. AXIAL LOAD FACTORS ENVELOPE PAYLOAD cg RESPONSES TO MOTOR IGNITION TRANSIENTS AND STEADY-STATE BOOST ACCELERATIONS
2. LATERAL LOAD FACTORS ARE PEAK PAYLOAD cg RESPONSES TO MAXIMUM NOZZLE DEFLECTIONS DURING ALL STAGES OF BOOST FLIGHT
3. AXIAL AND LATERAL LOAD FACTORS SHOULD BE APPLIED SIMULTANEOUSLY
4. POSITIVE AXIAL LOAD FACTOR INDICATES TENSION AT THE PAYLOAD INTERFACE



# PAYLOAD DYNAMIC MODE FREQUENCY REQUIREMENTS



MODE	LLV1	LLV2	LLV3
AXIAL <sup>(1)</sup>	> 30 Hz	> 30 Hz	> 30 Hz
LATERAL <sup>(2)</sup>	> 15 Hz	> 12 Hz	> 11 Hz

1. AXIAL MODE FREQUENCY REQUIREMENTS AVOID DYNAMIC COUPLING BETWEEN PAYLOAD AND BOOSTER IGNITION-FORCING FUNCTIONS
2. LATERAL MODE REQUIREMENTS AVOID DYNAMIC COUPLING BETWEEN PAYLOAD AND FIRST BENDING MODE OF THE LAUNCH VEHICLE

18 AUG 93

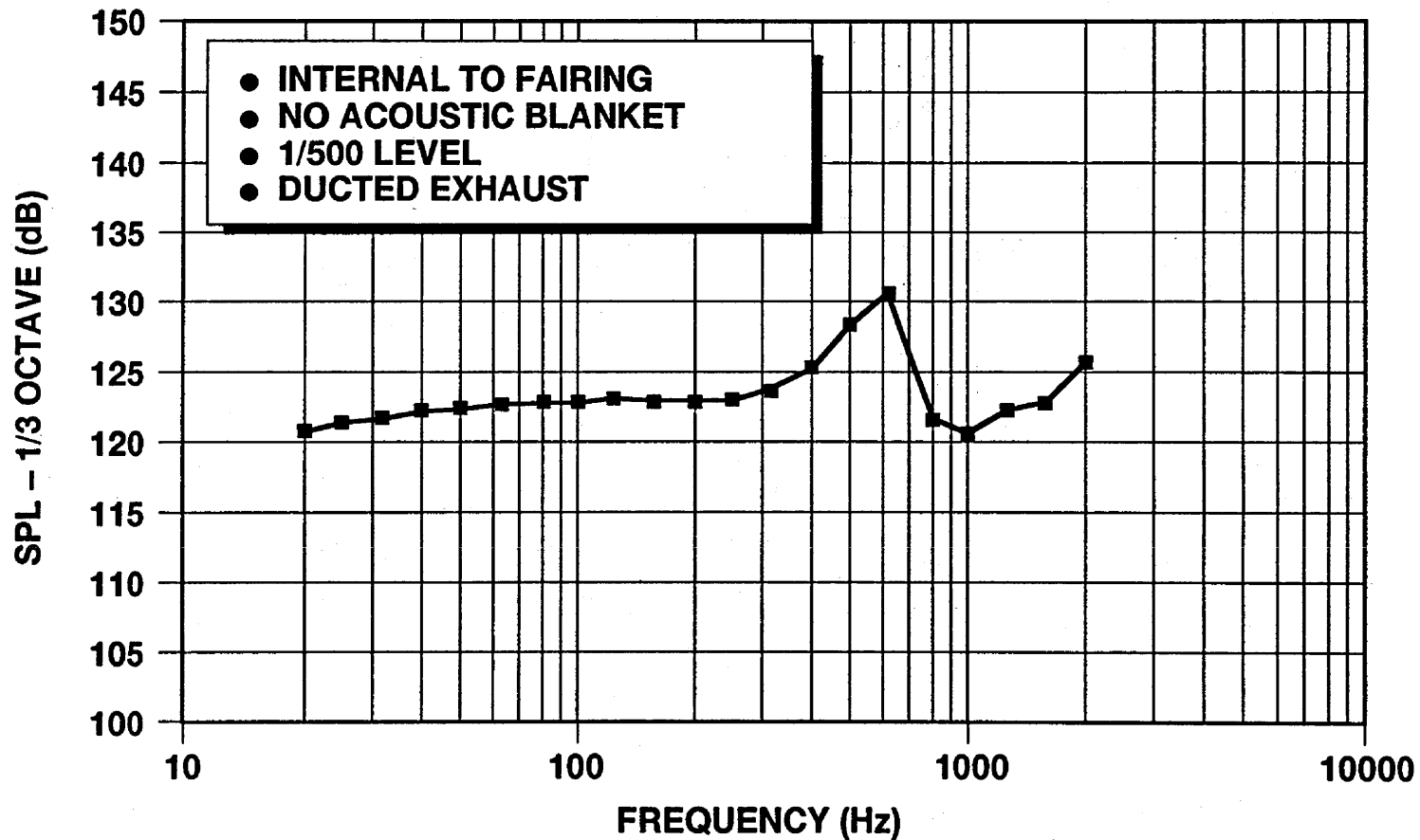


# LLV1 LAUNCH ACOUSTIC ENVIRONMENT



## PRELIMINARY

OVERALL SOUND PRESSURE: 137.3 dB

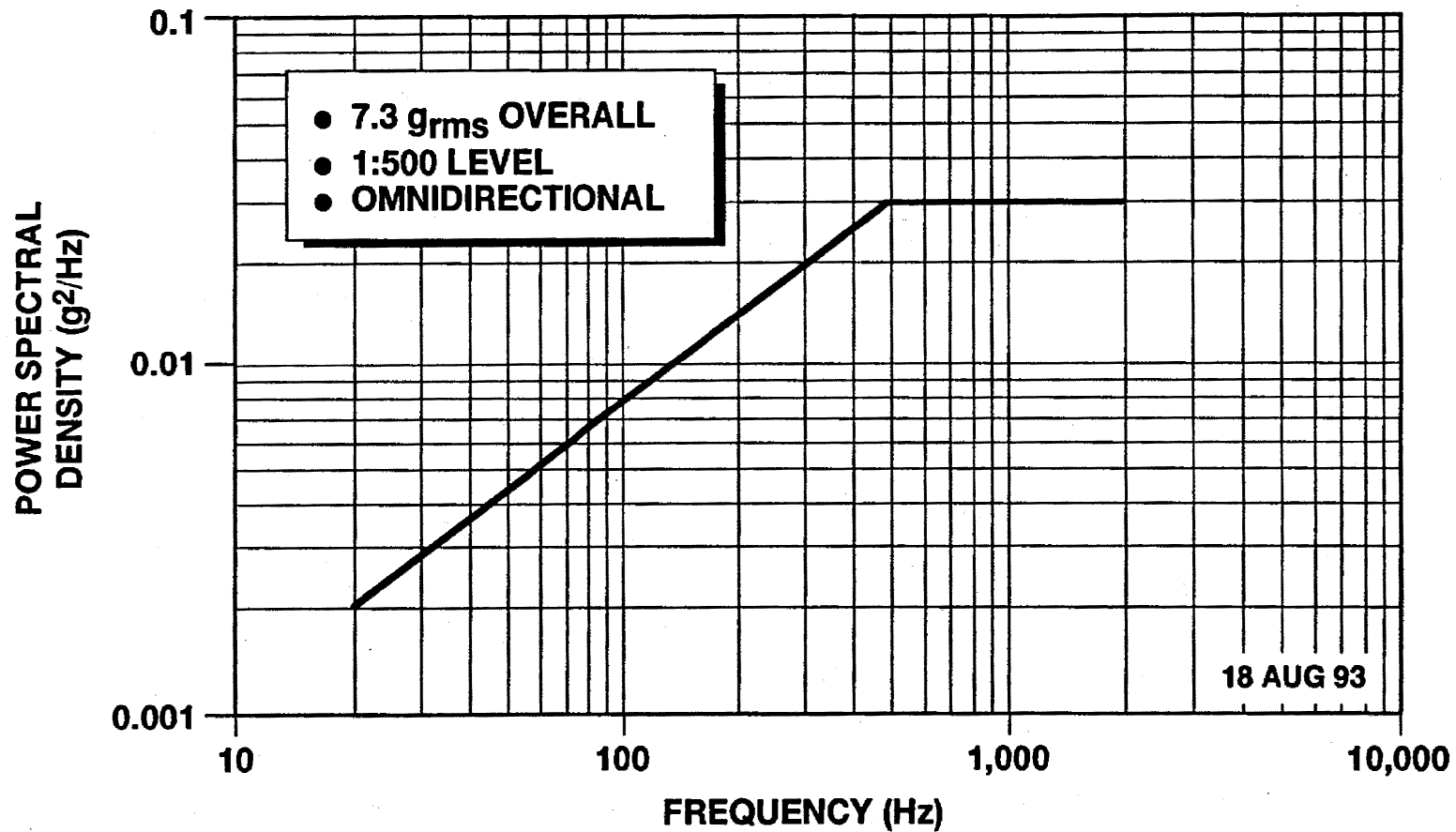




# LLV1 RANDOM VIBRATION ENVIRONMENT AT PAYLOAD I/F



PRELIMINARY

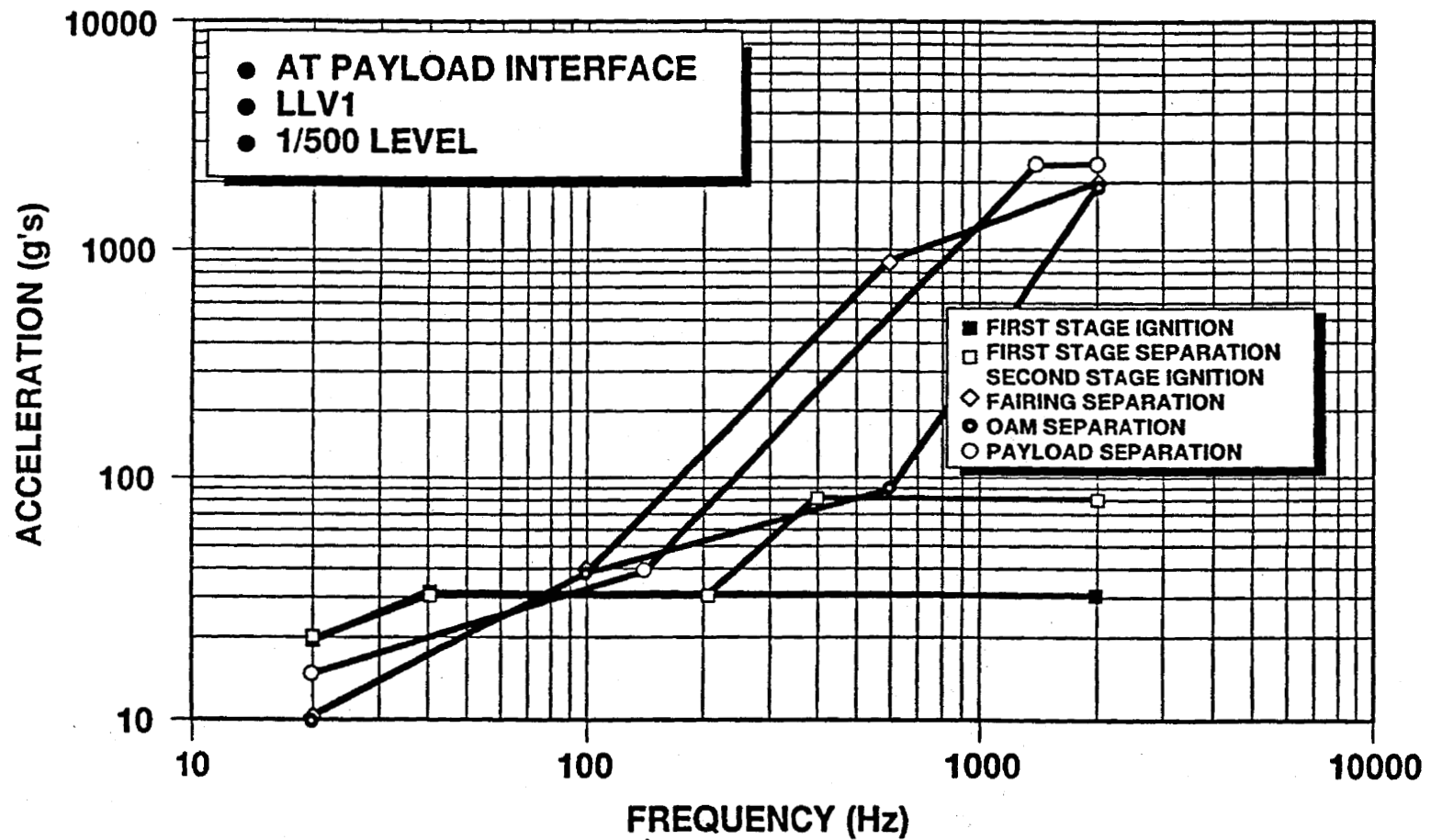




# LLV1 SHOCK SPECTRA



PRELIMINARY

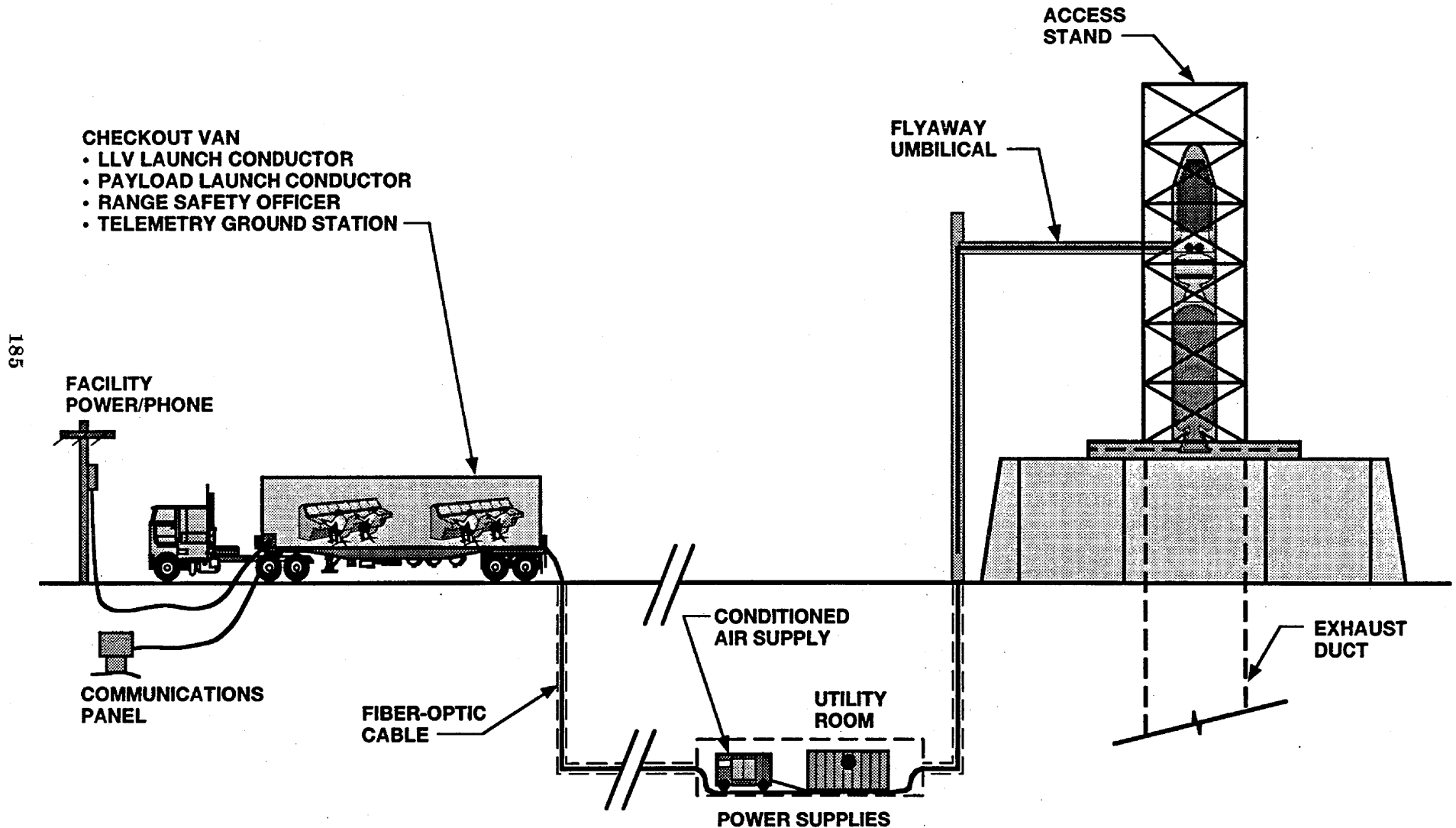




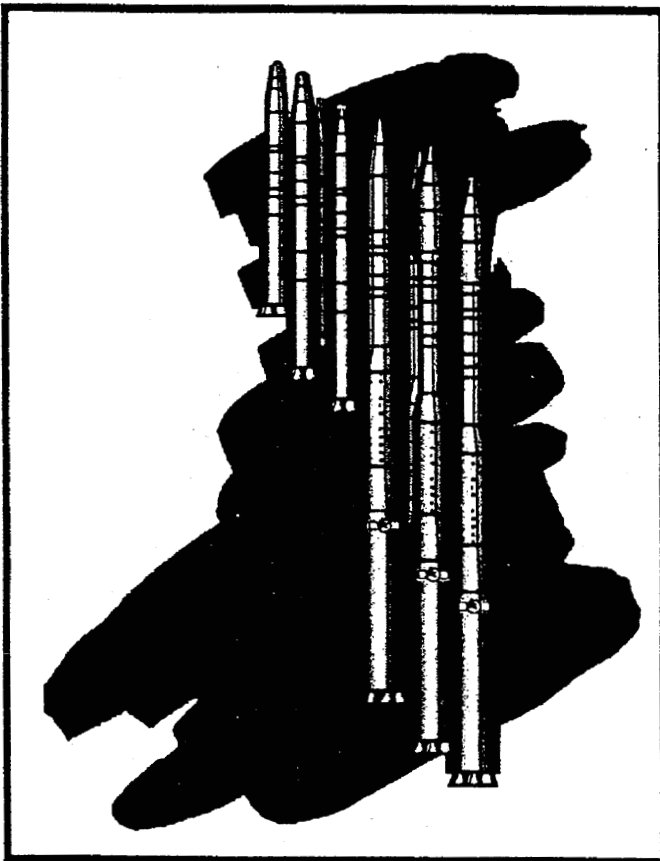




# LAUNCH SUPPORT







**USAF**  
**Reentry Systems Launch Program**

# **MSLS**

## **Multi-Service Launch System**

**Reliable, Cost Effective  
Test Vehicles for Tomorrow**

**MARTIN MARIETTA**

## **Reentry Systems Launch Program (RSLP)**

---

- **1972 SECDEF Charter**  
" . . . a single DoD agency provides launch vehicle support . . . "
- **Tasking from Program Management Directive (PMD)**
  - **Booster Storage, Modifications & Refurbishments**
  - **Launch Services**
  - **Develop Test Launch Vehicles (MSLS)**
  - **Minuteman II Deactivation**
- **Emerging Activities**
  - **START**

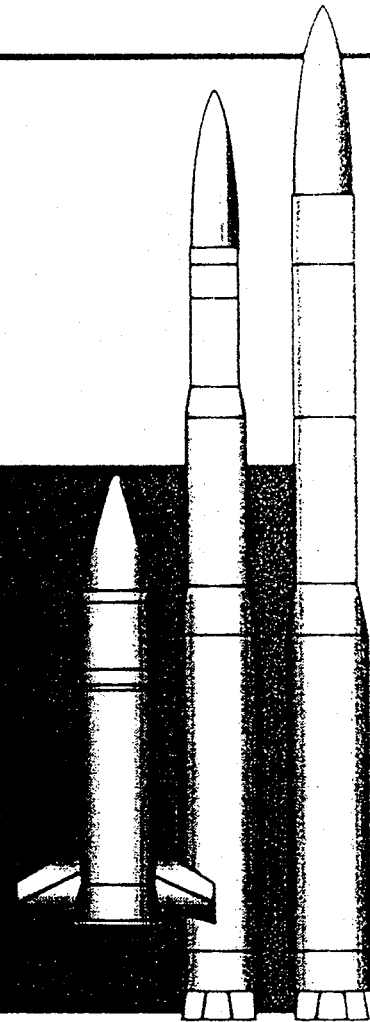
# The Logical Evolution



RSLV

- Single Fixed Configuration
- Aging Guidance Electronics
- Single Launch Site WR
- Rigid Weapons System Interfaces
- High Infrastructure Cost
- Escalating Launch Costs

- Multiple Configuration
  - Sounding Rocket
  - ICBM Class
  - Space Launch Vehicle
- Flexible Interfaces
- Modern Modular AVE Components
- Multiple Launch Sites
- Low Infrastructure Cost
- Low Launch Cost



MSLS

# MSLS Organization



## **MSLS Concept**

---

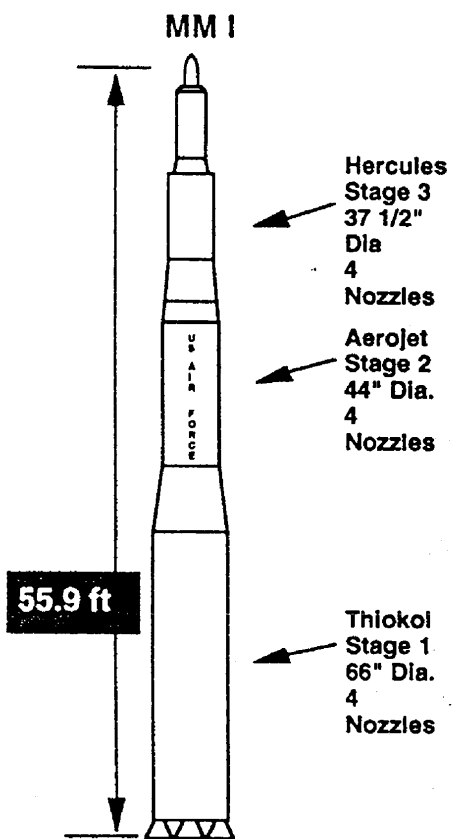
- **Maximize Use of Proven Off-the-Shelf Hardware**
  - **Reliability**
  - **Low Development Cost & Risk**
- **Standard Hardware Across Applications**
  - **Structure & Shroud**
  - **Guidance & Control (Boost & Postboost)**
  - **Flight Termination Systems**
  - **Payload Interfaces & Dispensing**
  - **Telemetry**
  - **Attitude Control System**
- **Proof Test at System Level Before Flight**

# MSLS Capabilities Overview

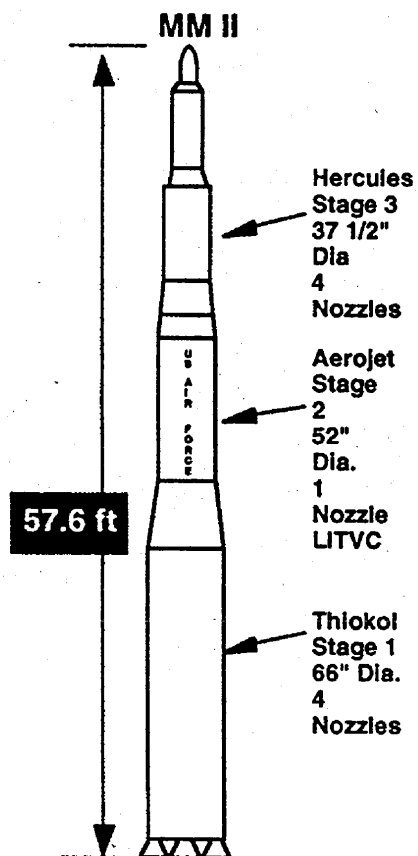
- **Basic Vehicle**
  - Boosters, MMI, MMII, & Variants
  - Structure & Shroud
  - Avionics
    - Guidance, Navigation & Control System (GNCS)
    - Telemetry & Instrumentation System (TIMS)
    - Electrical Power & Distribution System (EPDS)
    - Airborne Range Safety System (ARSS)
    - Attitude Control System (ACS)
  - Payload Deployment Subsystem
- **Options**
  - Sounding Rocket Vehicles
  - Space Launch Vehicles
- **Enhancements**
  - Video
  - Fragmentation
  - Separation of AVE from Stage III
  - Encryption (START Limited)
  - GPS Positioning
  - Uplink Capability



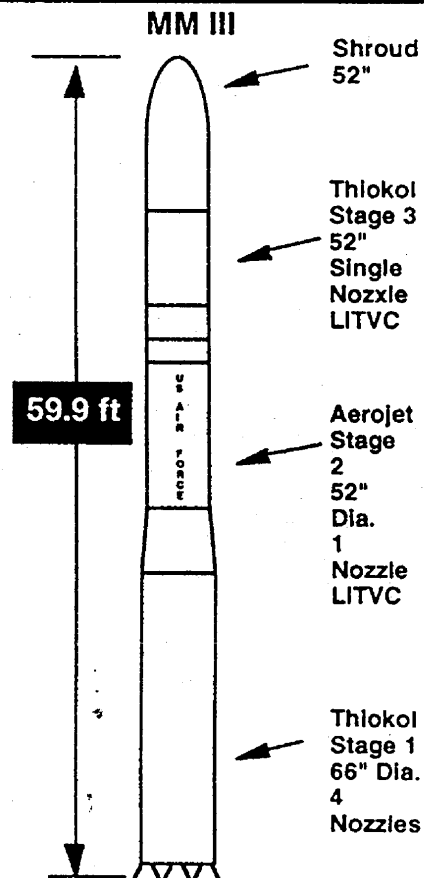
# Minuteman Configurations



Liftoff Weight(lbs) 68000  
Liftoff Thrust (lbs) 200000



72000  
200000

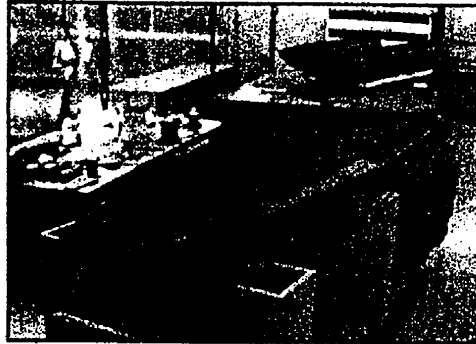


75000  
200000

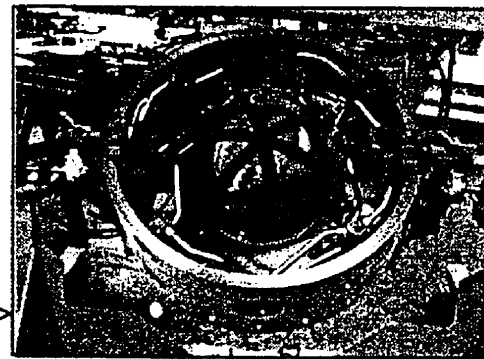
## MSLS Front Section-Pictures



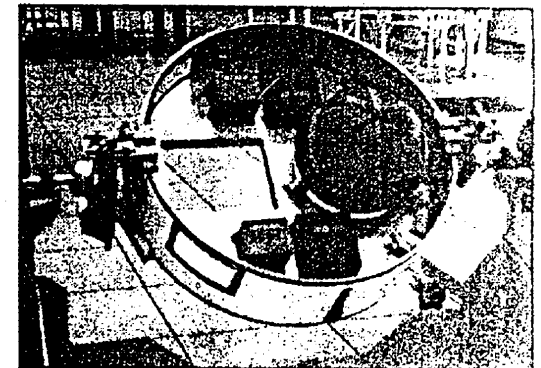
Shroud



Avionics Wafer



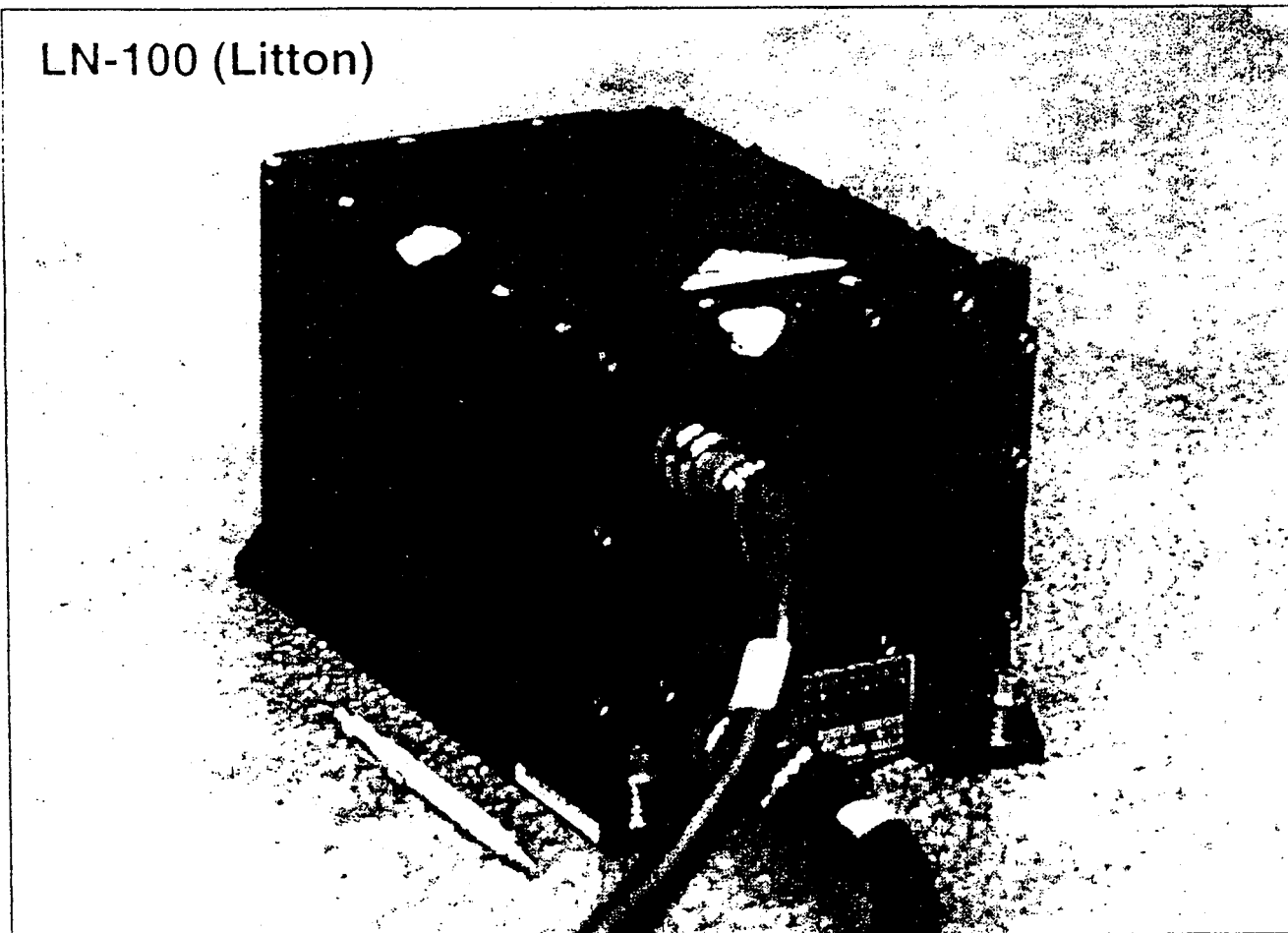
ACS Wafer



ARSS Wafer

# MSLS Guidance System

LN-100 (Litton)

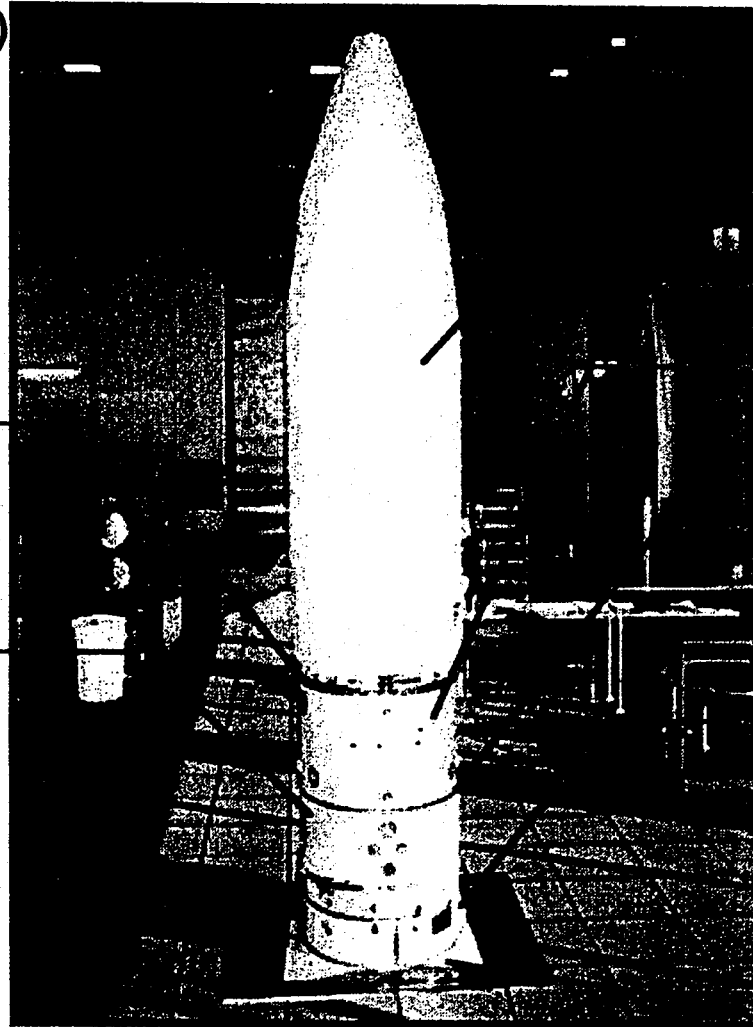


# MSLS Front Section & Shroud (FSS)

(Development Test Unit)

Shroud Separation  
Joint

Attitude Control  
System (ACS)  
Wafer



Shroud

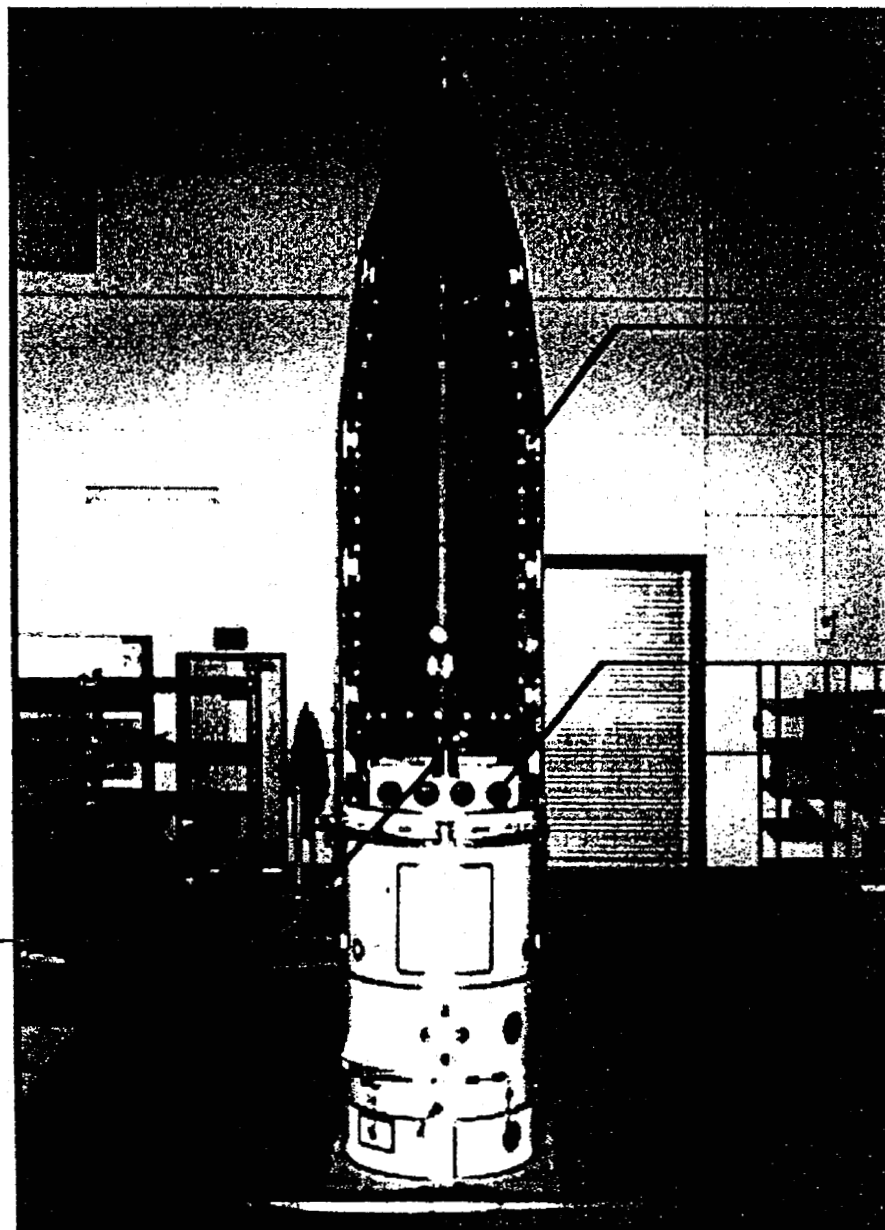
Avionics  
Wafer

Stage III  
Separation  
Joint

Airborne  
Range Safety  
System  
(ARSS) Wafer

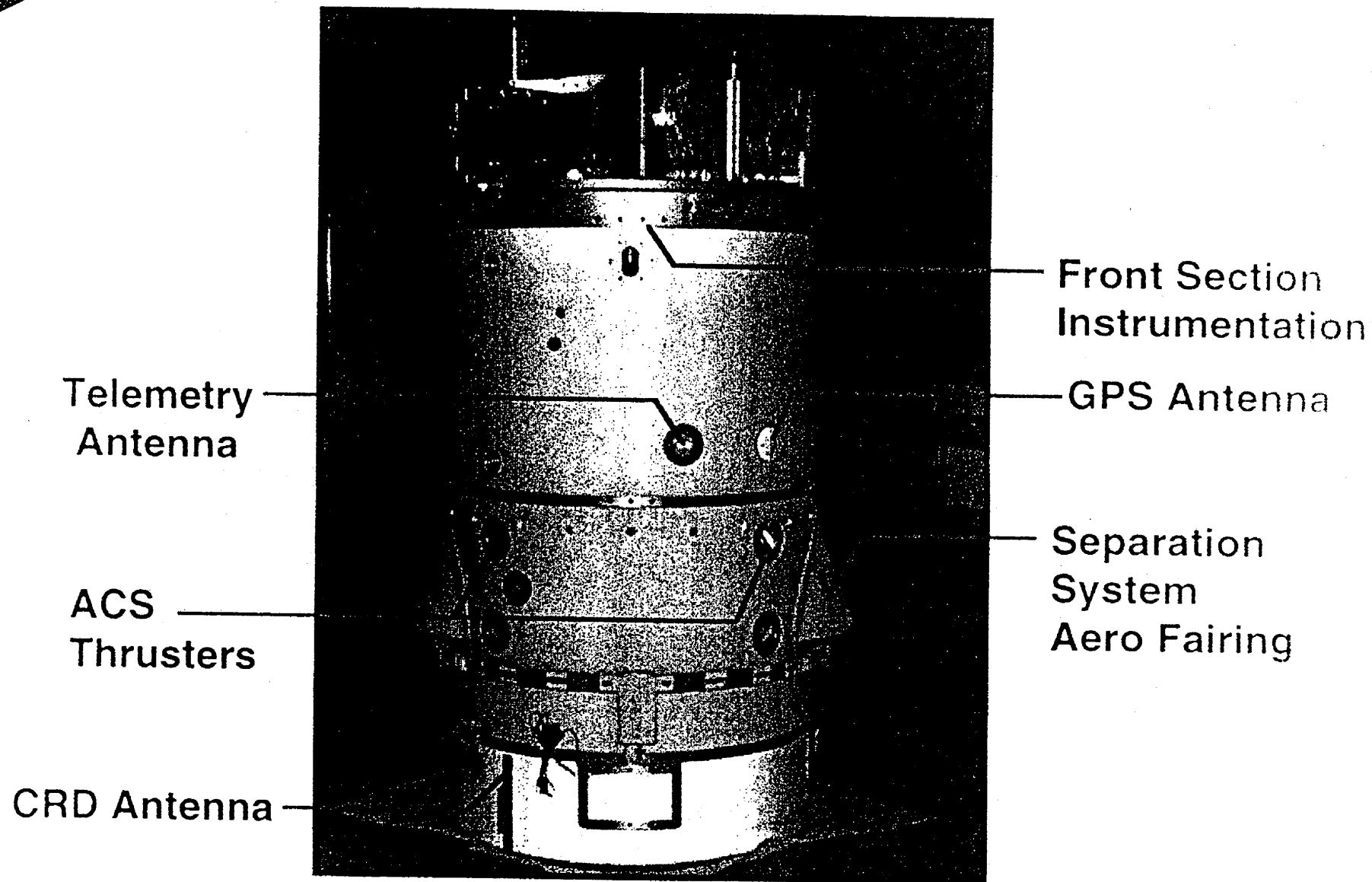
Stage III Interface

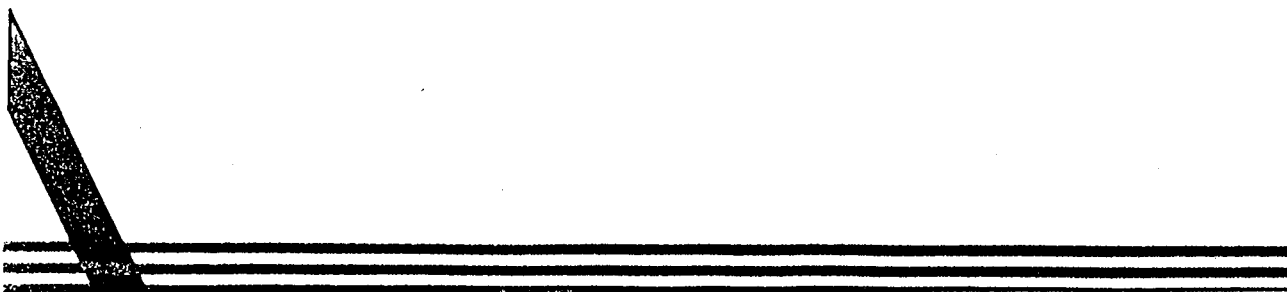
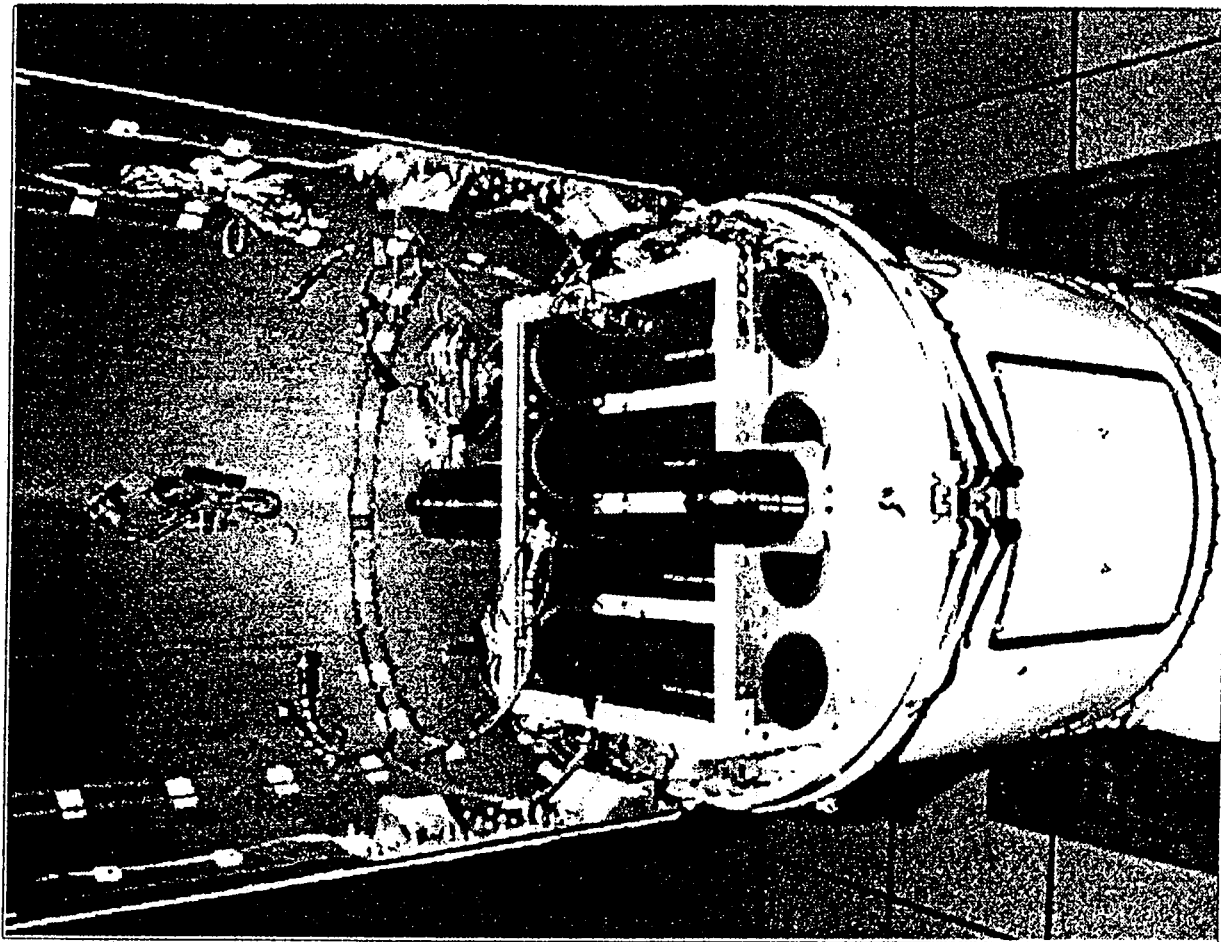
Retro Rocket  
Motors



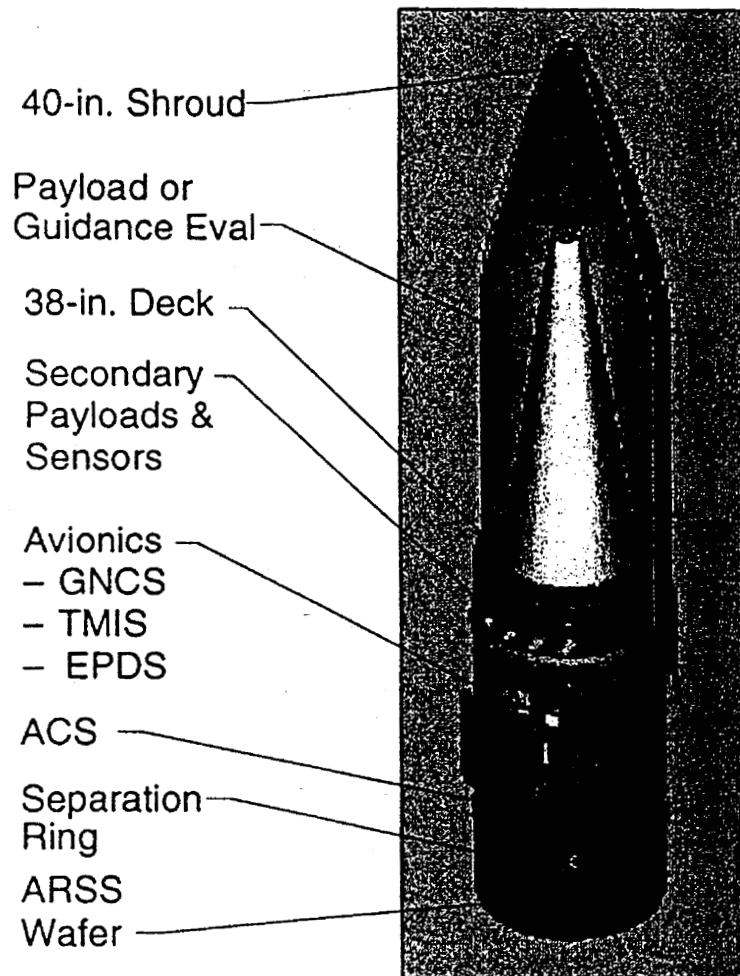
Shroud  
Separator  
System

Secondary  
Payload Rack





# Basic Configuration Components

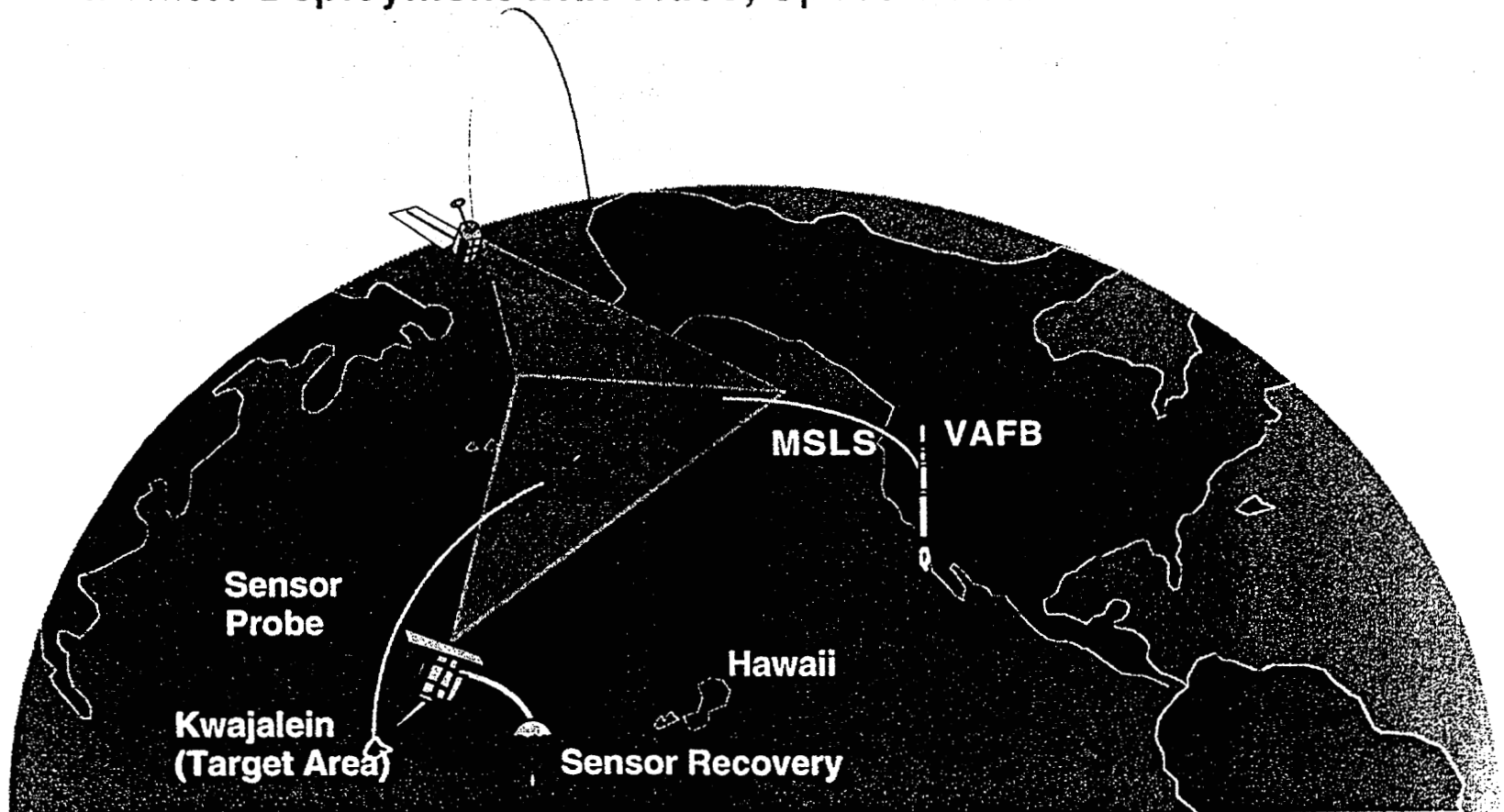


- **Applications**
  - Enhanced S/R
  - Pen-Aids Deployment Missions
  - Ground-Based Sensors & Interceptors
  - Space-Based Sensors & Interceptors
- **Capacities Using MMII**
  - 27 Auxiliary Payloads
  - ICBM Ranges with Varying Reentry Angles
  - Payloads Up to 1450 lb
  - 4200-nmi Max Downrange

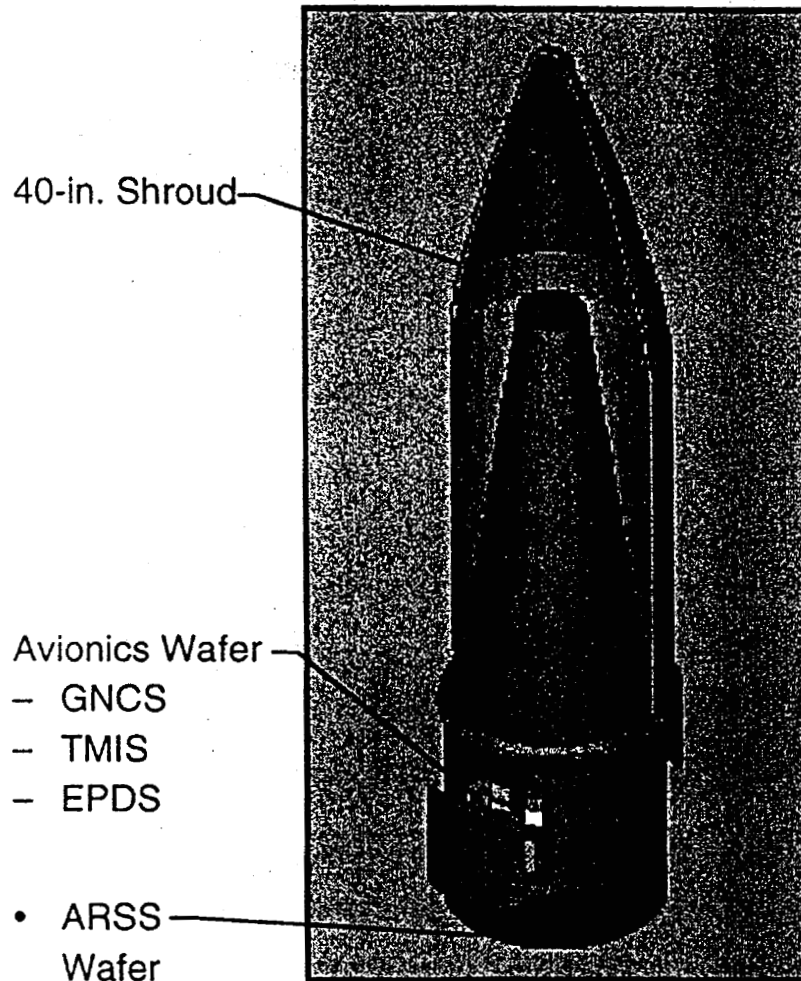


## Basic Mission Scenario

- Ground- or Space-Based Sensors & Interceptors
- Deploy RVs, Replicas, & Balloons
- Monitor Deployment with Video, Spectrometers & T/M Downlink



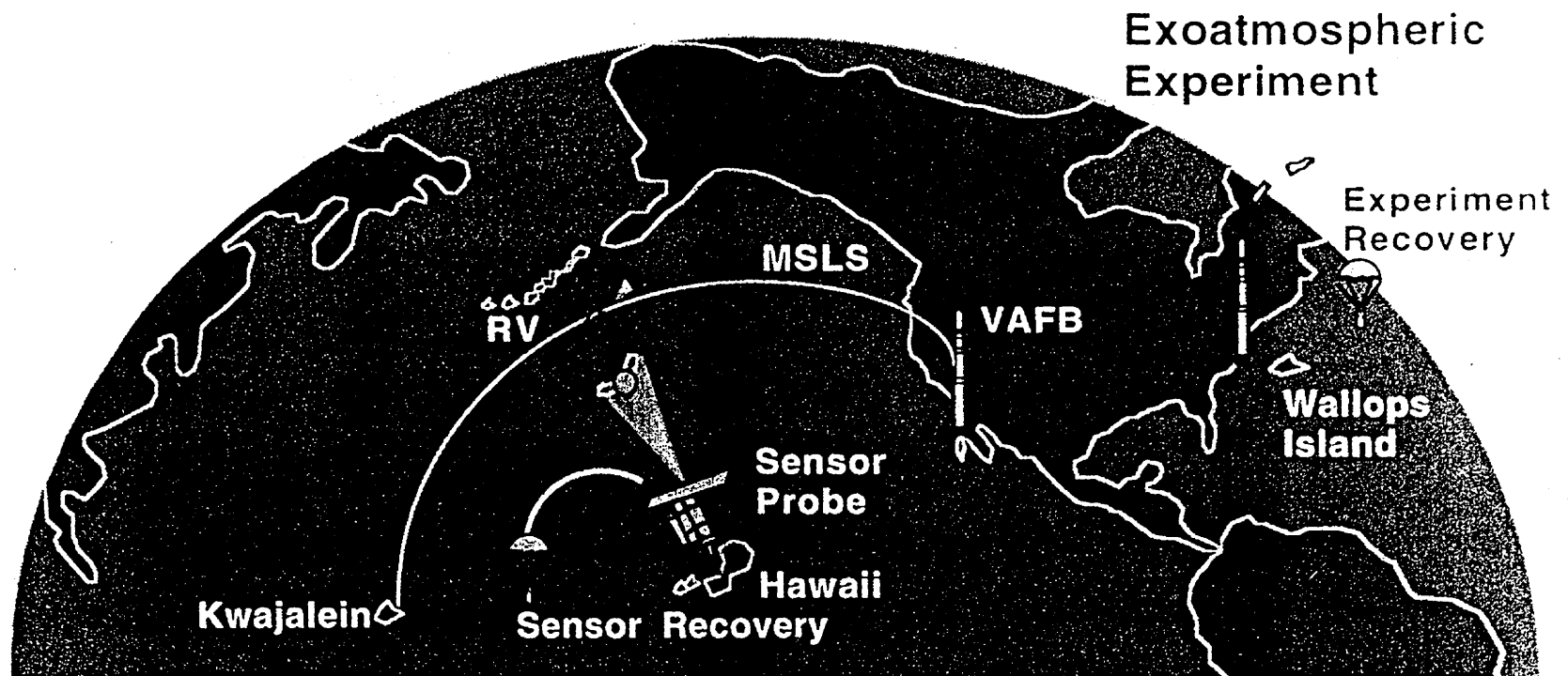
# Simplified Configuration Components



- Applications
  - Sounding Rockets
  - Target Missions
  - Ballistic Missiles
- Capacities Using MMII
  - Maximize Exoatmospheric Flight
  - Payloads Up to 1300 lb
  - Altitudes Up to 2M ft (600 Km)
  - 4200-nmi Max Downrange

## Simplified Mission Scenario

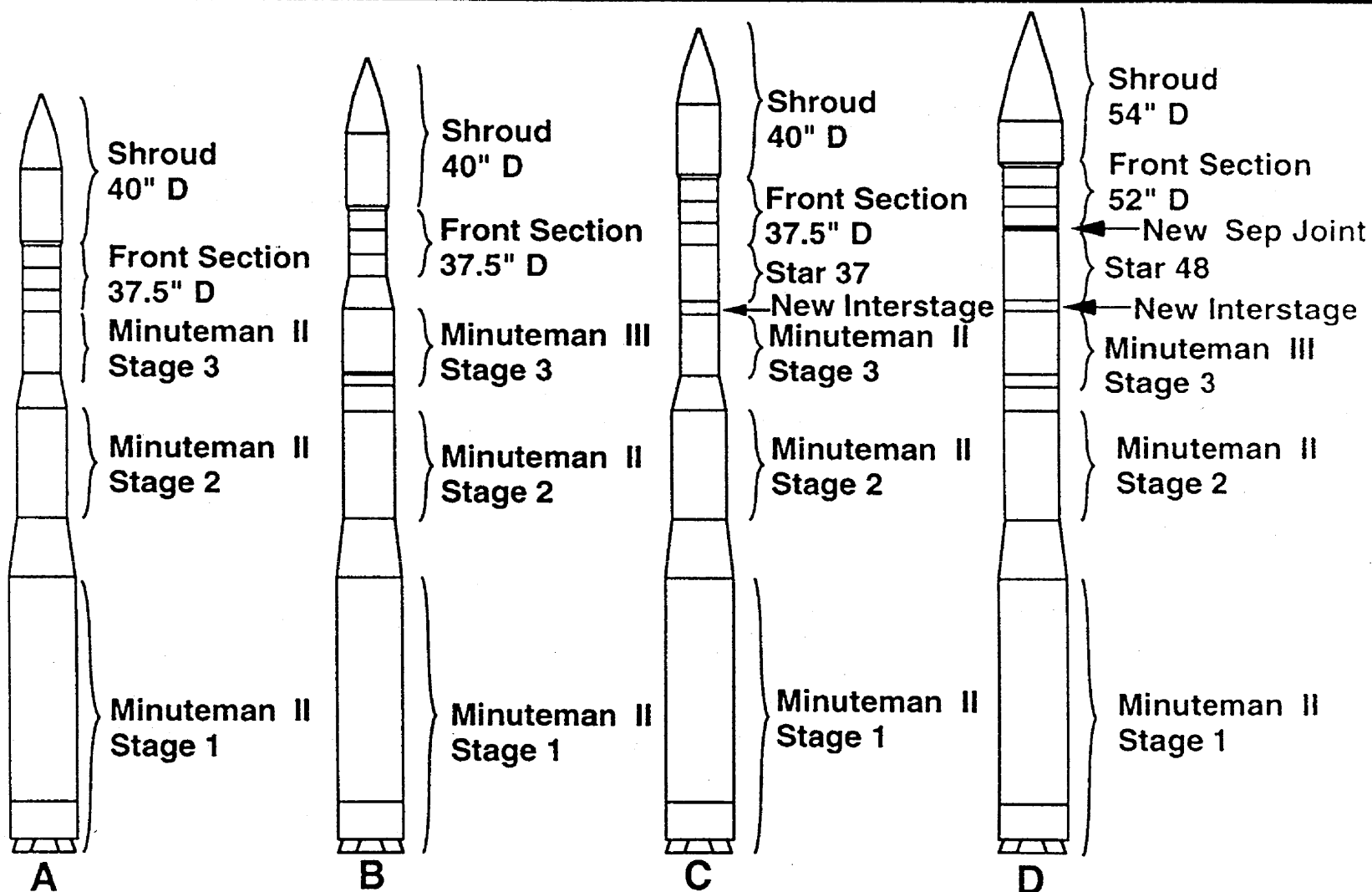
- Exoatmospheric Experiments
- Sensor Missions





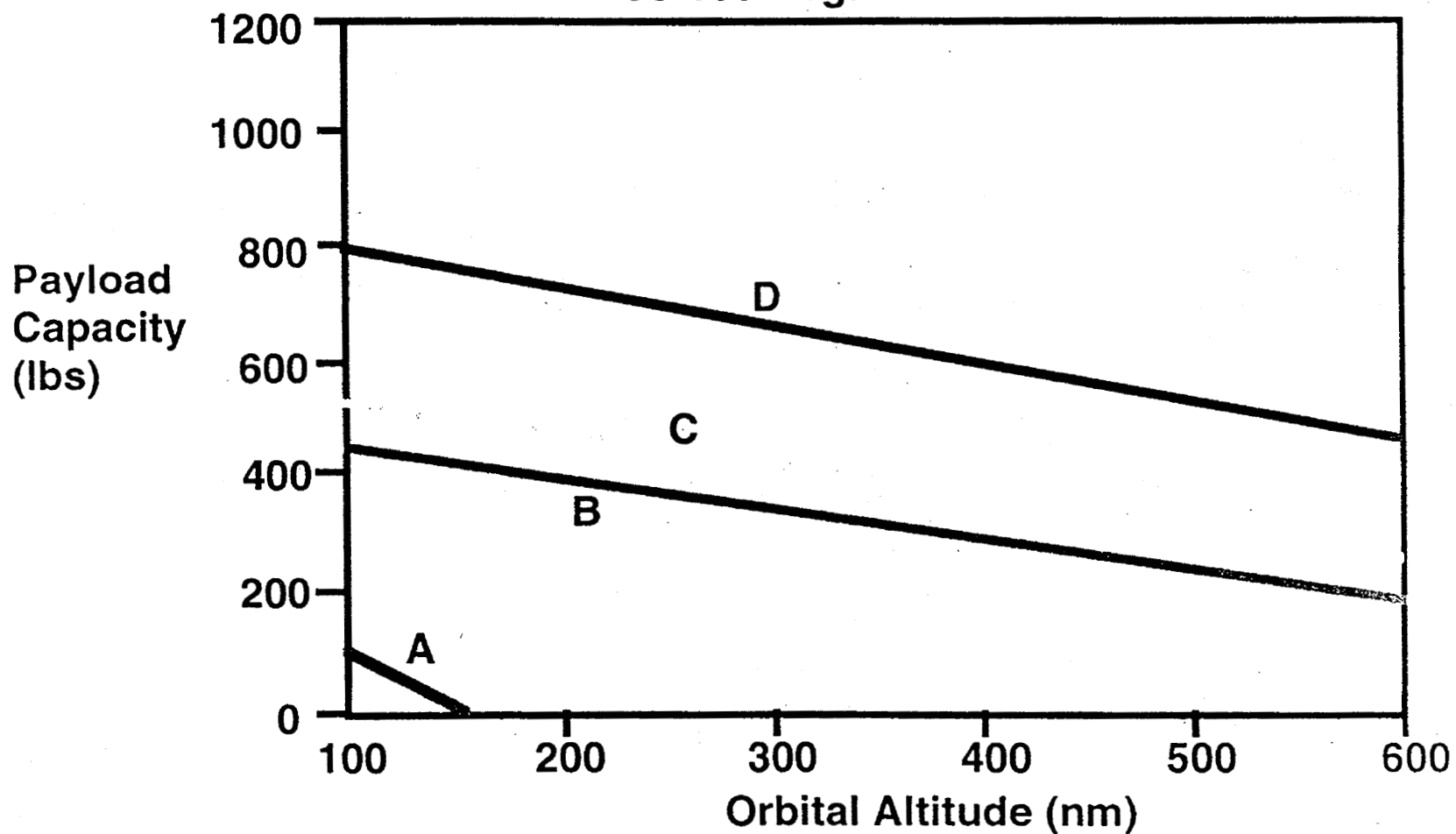
# MSLS Space Launch

# Minuteman II Space Launch Vehicle Configurations

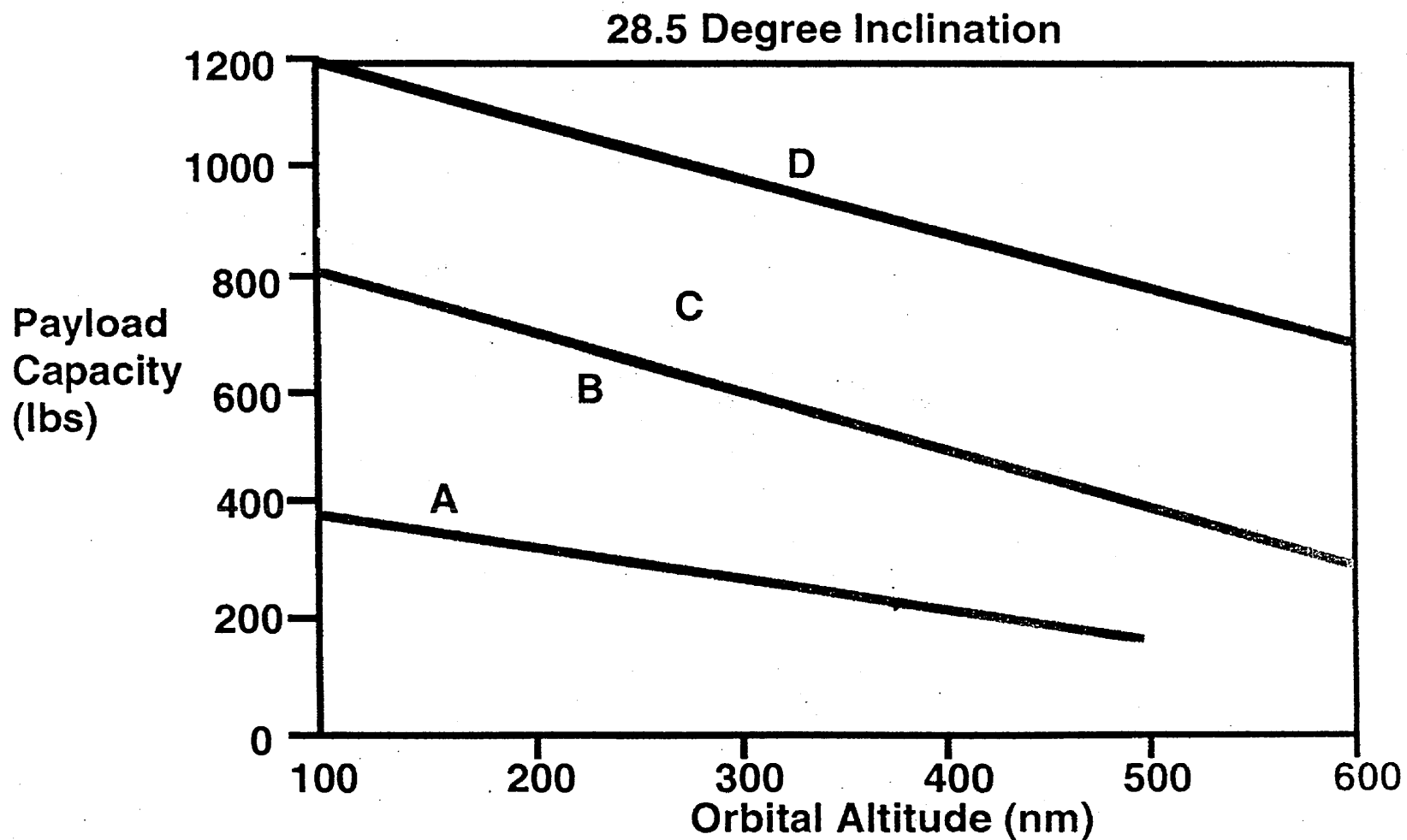


# WTR Performance Capabilities

90-108 Degree Inclination

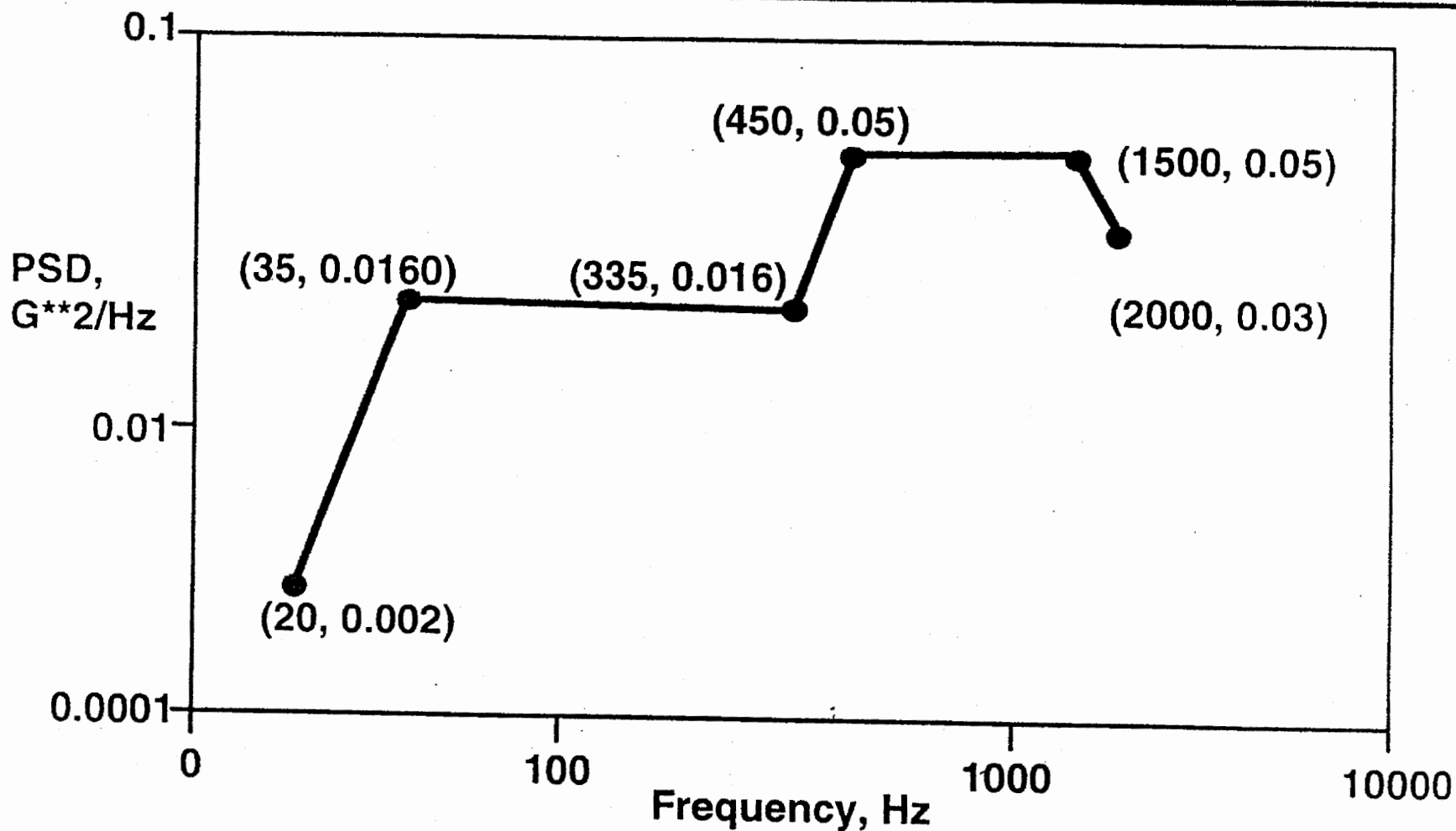


# ETR Performance Capabilities



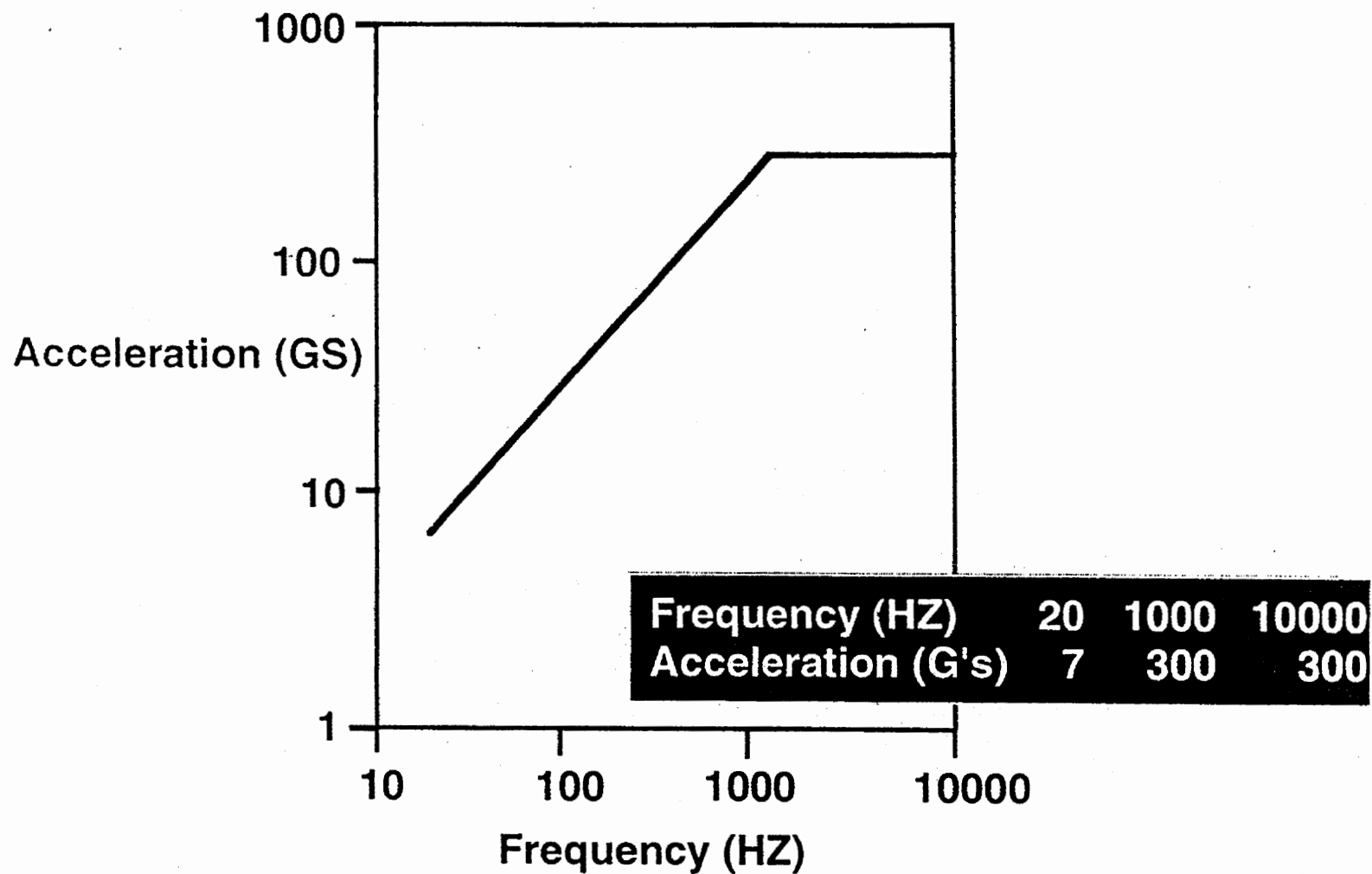
# Minuteman P/L & Component Vibration Requirement

Pad Launch





## Maximum Allowable Shock to the Payload from the FSS

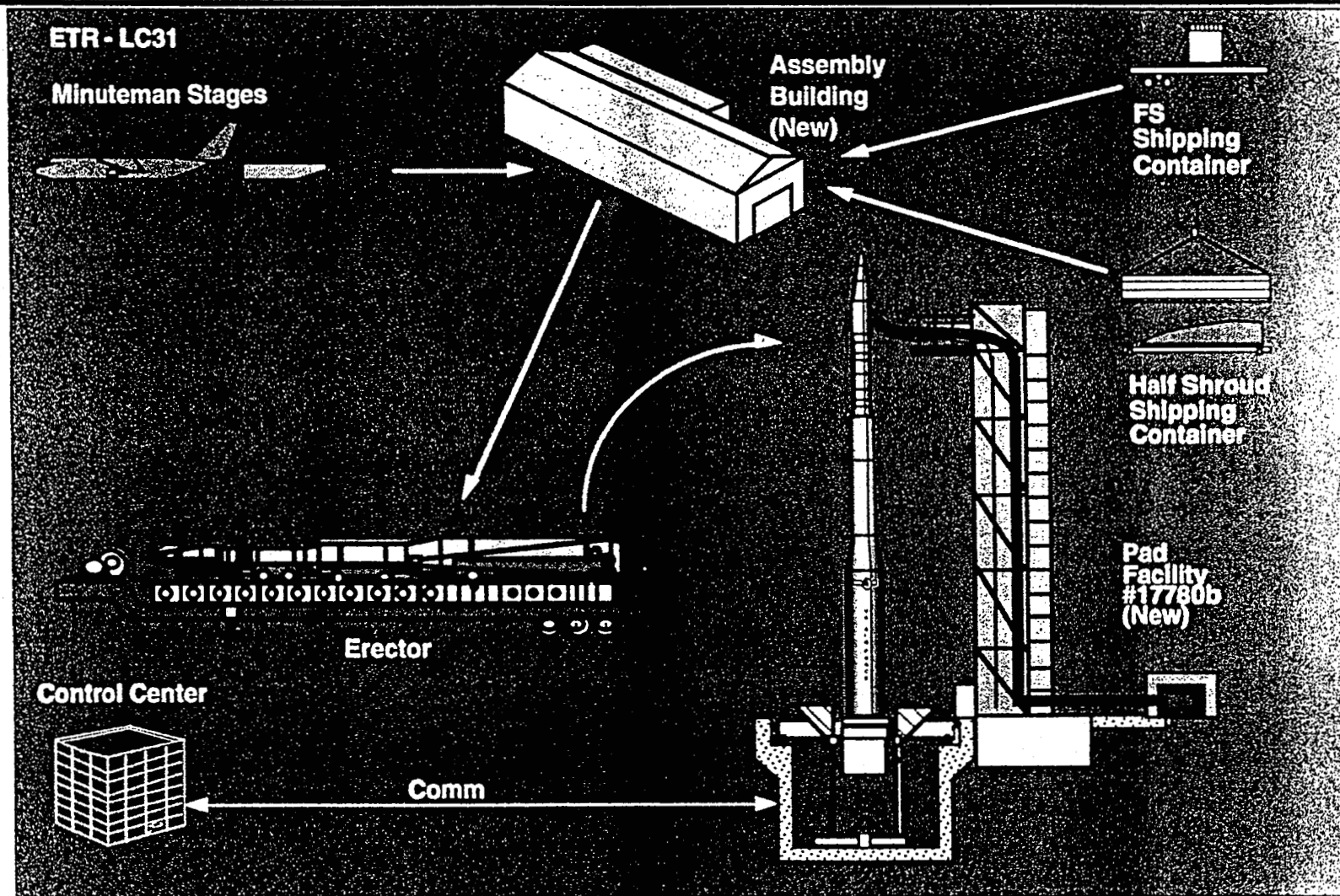


## **MSLS Space Launch Plan**

---

- **NASA to Fund a \$24M, 3 Satellite 3 Year Pilot Program**
- **USRA Payloads Fly Polar Orbits from Western Test Range**
- **Total Air Force Launch Vehicle Costs To NASA Not to Exceed \$15M**
- **Air Force Launch Vehicle of Choice Is MSLS Configuration B**
- **Authority To Proceed - 10/93**
- **Initial Launch Capability - 10/95**

# Minuteman II Space Launch Complexes



## MSLS Space Option

	<b>Martin Marietta Average Recurring</b>	<b>Government Costs per Flight</b>	<b>Total Cost</b>
<b>Sub-Orbital</b>	<b>1.4-2.0</b>	<b>2.0</b>	<b>3.4-4.0</b>
<b>Orbital</b>			
<b>Config A</b>	<b>2.2</b>	<b>2.0</b>	<b>4.2</b>
<b>Config B</b>	<b>2.2</b>	<b>2.2</b>	<b>4.4</b>
<b>Config C</b>	<b>3.5</b>	<b>2.0</b>	<b>5.5</b>
<b>Config D</b>	<b>4.2</b>	<b>2.2</b>	<b>6.4</b>



## **MSLS Summary**

---

- **There are 450 Minuteman II's Available for AF Use**
- **The AF Reentry System Program Office (RSLP) Is the Home of MSLS**
- **MSLS Is a Reliable, Cost Effective Application of Retired Minuteman**
- **The MSLS Conversion for Space Is Simple and Inexpensive**



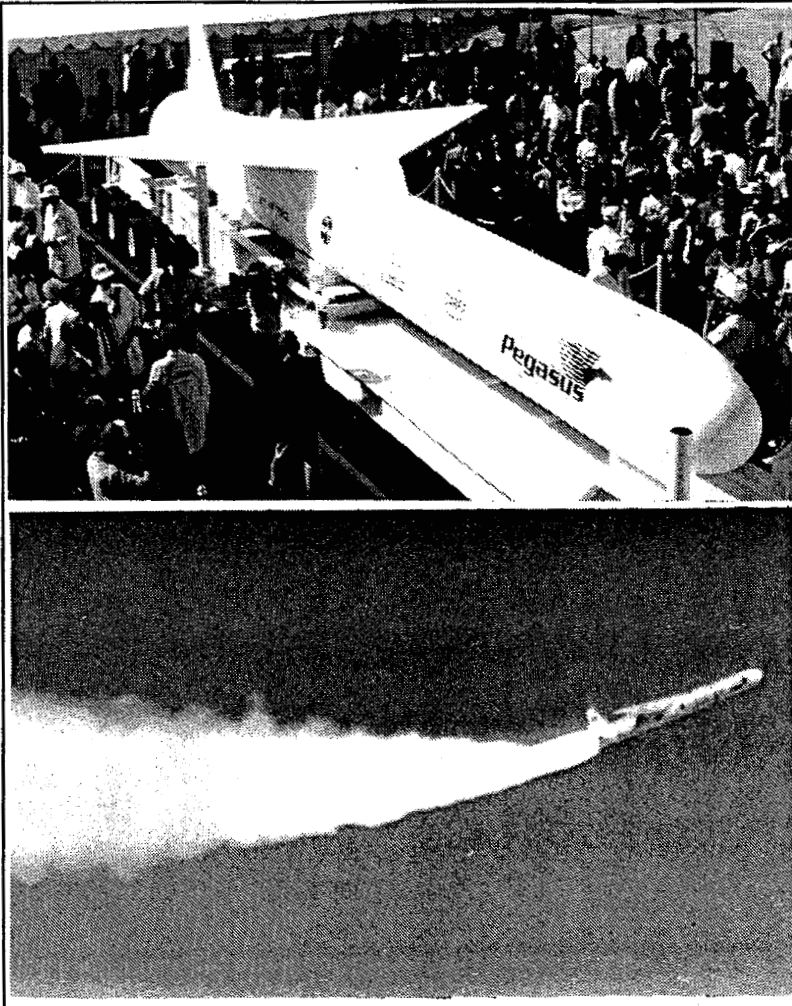


Orbital  
Sciences  
Corporation



## Pegasus Space Launch Vehicle

Orbital  
Sciences  
Corporation



- 1,000 lb Payload Class Space Launch Vehicle With Major Performance/Price and Operational Flexibility Advantages
- Air-Launched from B-52 or L-1011 Aircraft; East and West Coast Launch Bases and Ranges
- Delivers Scientific, Communications, Environmental Monitoring, Military and R&D Satellites to LEO; Limited GEO and Planetary Capability
- Four Launches Conducted in 1990-1993; Firm and Option Vehicles Under Contract for ARPA, NASA, U.S. Air Force, BMDO, Commercial and International Customers
- Substantial Customer-Funded Product Upgrades (Pegasus XL) to Be Operational in 1994; Growth Configurations Available c. 1996-1997
- Price Range of \$8 – 12M



## Pegasus Air-Launched Booster



- Privately Developed Low-Cost Space Launch Vehicle
- First New U.S. Unmanned Launch Vehicle Developed in 20 Years

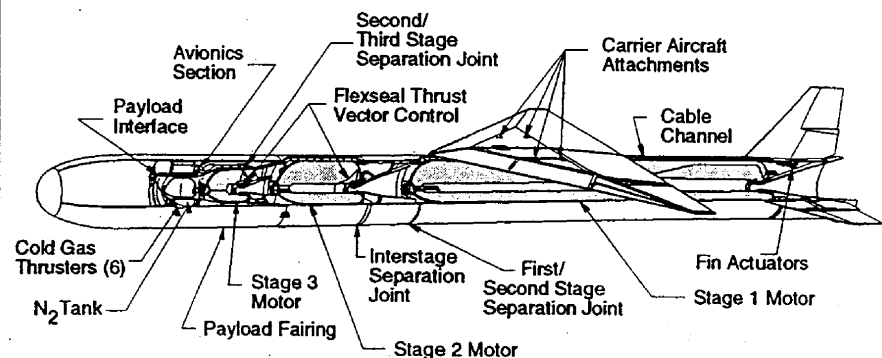
- WINGED PEGASUS PROVIDES NEW AND UNIQUE SPACE LAUNCH CAPABILITIES
  - SIMPLE BUT ROBUST DESIGN
  - MINIMUM FACILITIES AND SUPPORT
  - SMALL ASSEMBLY & LAUNCH TEAMS
  - FLEXIBLE WORLD-WIDE OPERATIONS
  - MAXIMUM LAUNCH RESPONSIVENESS
- PEGASUS PROVIDES ENABLING CAPABILITY FOR NEW CLASS OF SPACE AND TRANSATMOSPHERIC MISSIONS

### GENERAL CHARACTERISTICS

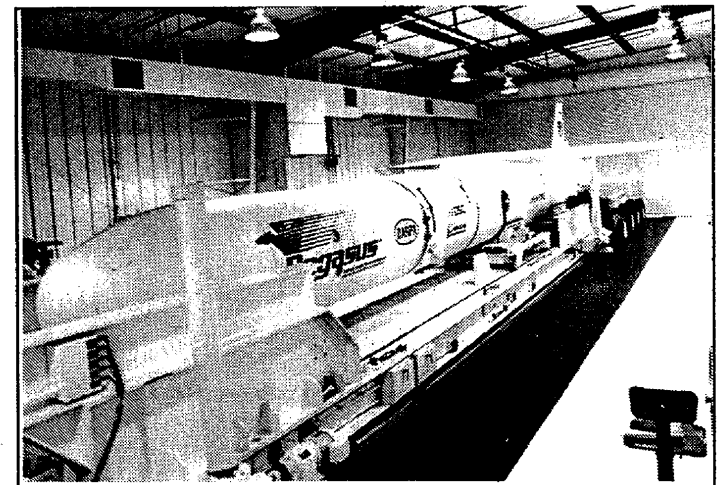
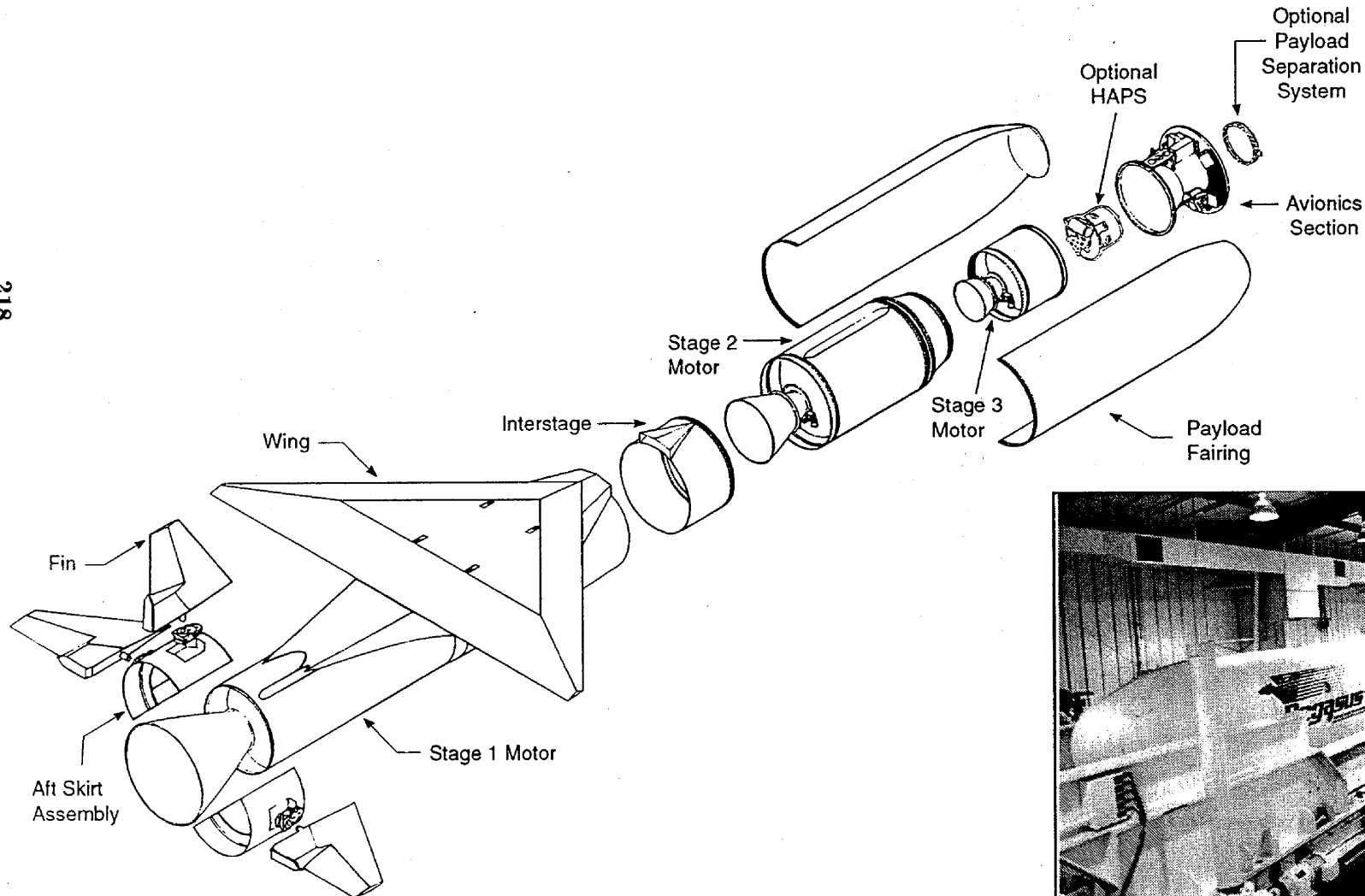
- 42,000 lb Gross Weight\*
- 400 – 1000 lb Payload
- 50 ft Long, 50 inch Diameter
- All Graphite-Composite Structure
- 3-Stage Solid Rocket Motors (Class 1.3 Propellant)
- 3-Axis Inertial Attitude Control (Advanced Electronics)
- Winged Vehicle for Lifting Ascent

\*Larger Versions in Development

### CONFIGURATION



## Vehicle Description

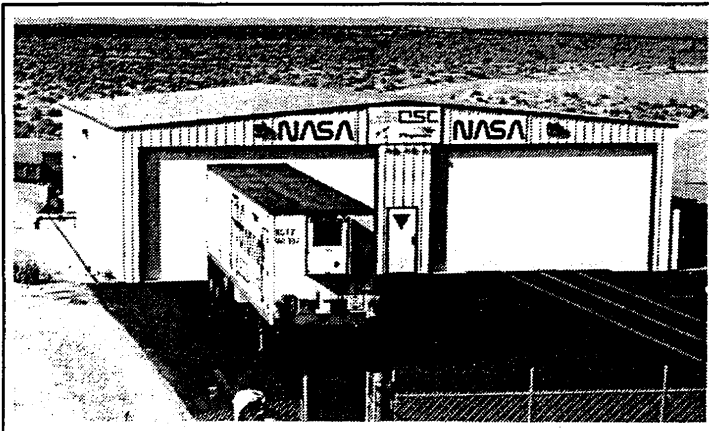


921015.12

# Pegasus Vehicle Integration



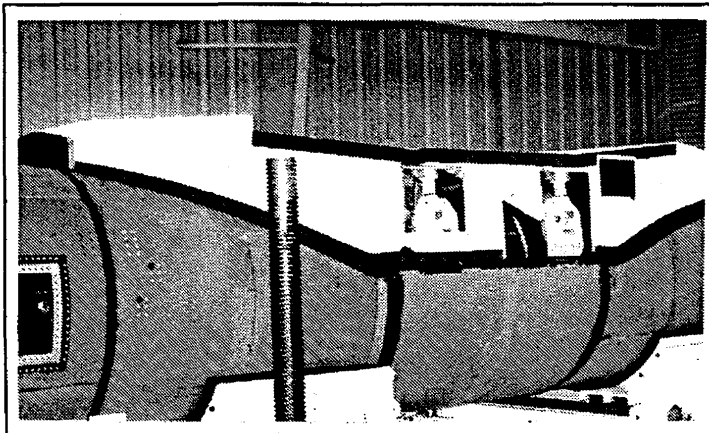
Vehicle Assembly Building



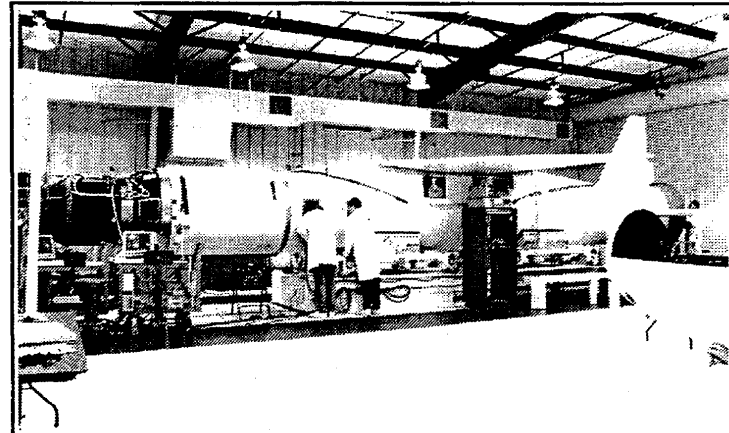
Assembly and Integration Trailer



Fillet Installation



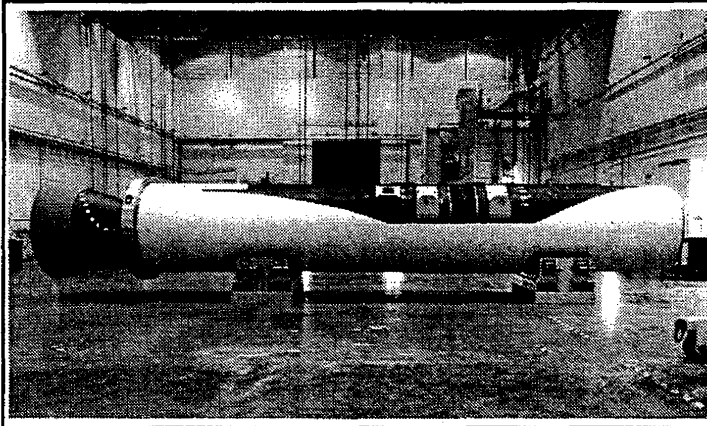
Pegasus Vehicle



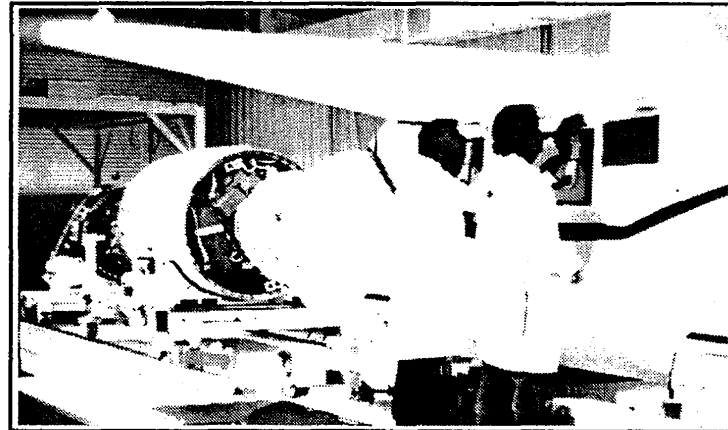
# Pegasus Air Launched Space Booster Flight Operations

Orbital  
Sciences  
Corporation  
**Osc**  
*Space Systems Division*

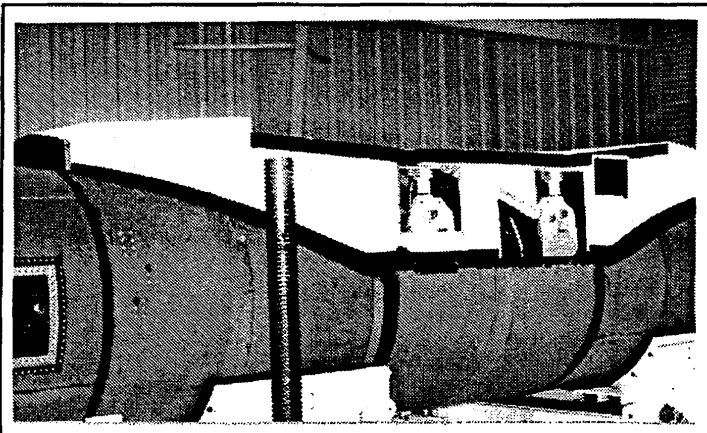
First Stage Motor



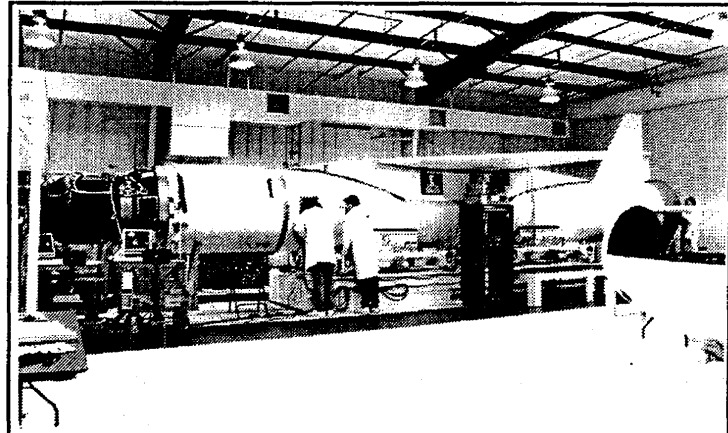
F1 Vehicle Integration



Fillet Installation



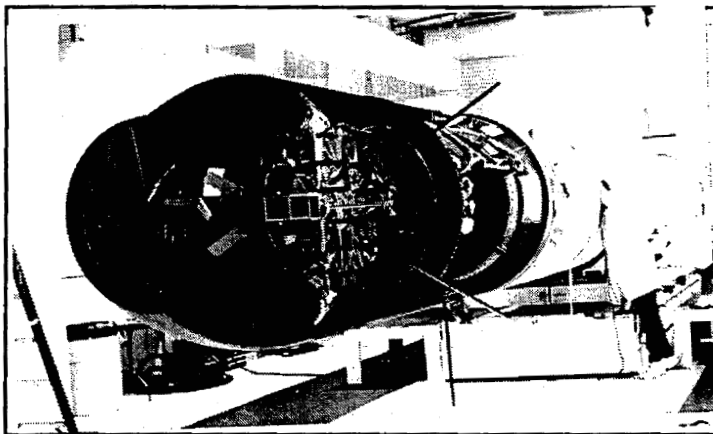
Pegasus F1 Vehicle



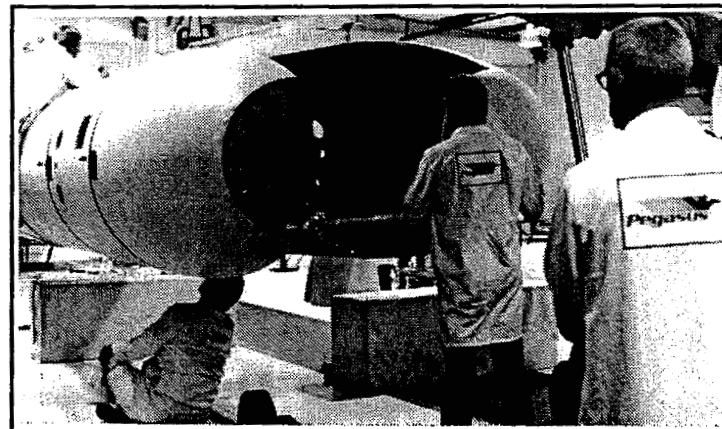
# Pegasus Air Launched Space Booster Flight Operations

Orbital  
Sciences  
Corporation  
**OSC**  
*Space Systems Division*

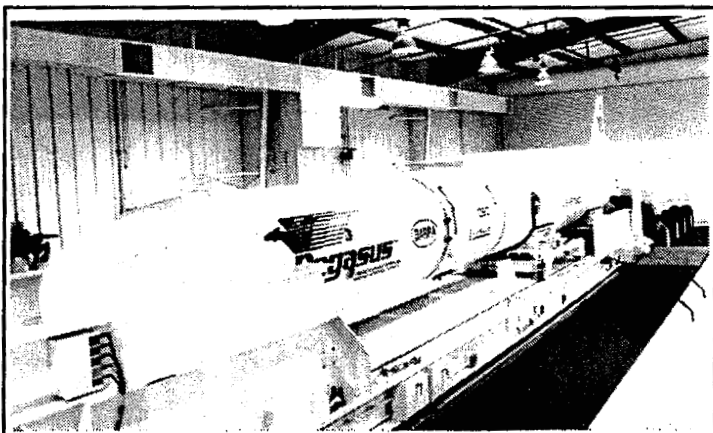
Pegasus F1 Vehicle



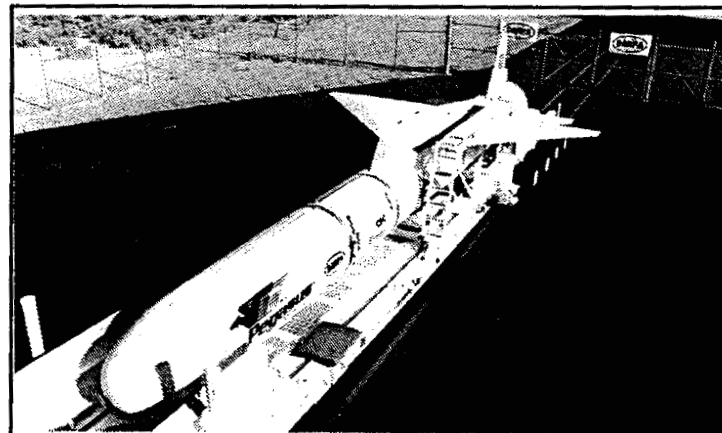
Fairing Installation



Pegasus F1 Vehicle



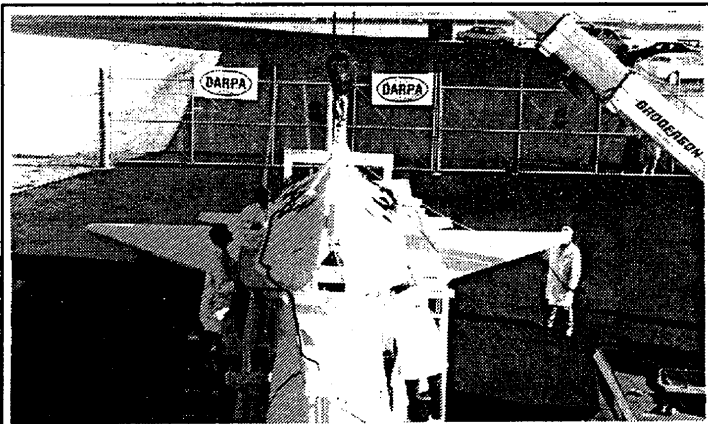
F1 Vehicle Ready for Pylon Adapter  
Installation



# Pegasus Air Launched Space Booster Flight Operations

Orbital  
Sciences  
Corporation  
***OSC***  
***Space Systems Division***

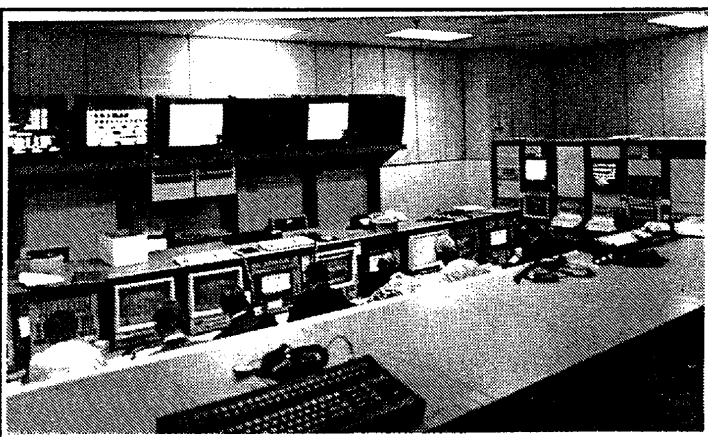
**Pylon Adapter Installation**



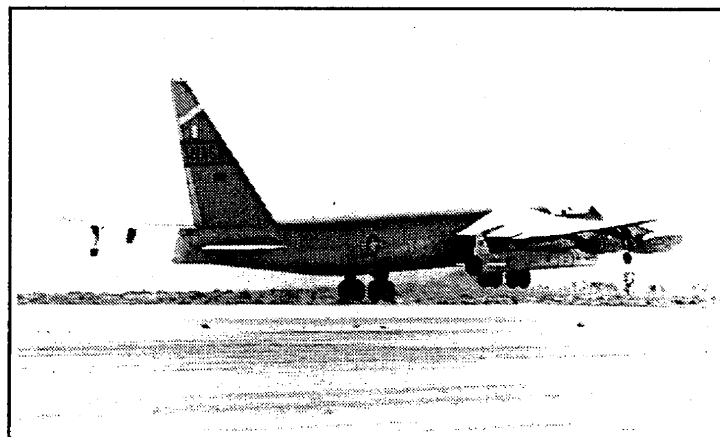
**F1 Vehicle Mated to B52**



**NASA DFRF Control Room**



**Pegasus F1 B52 Take-Off**

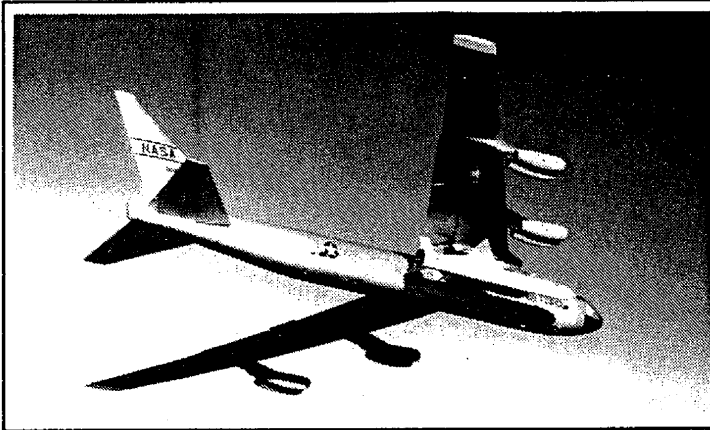


00726.04

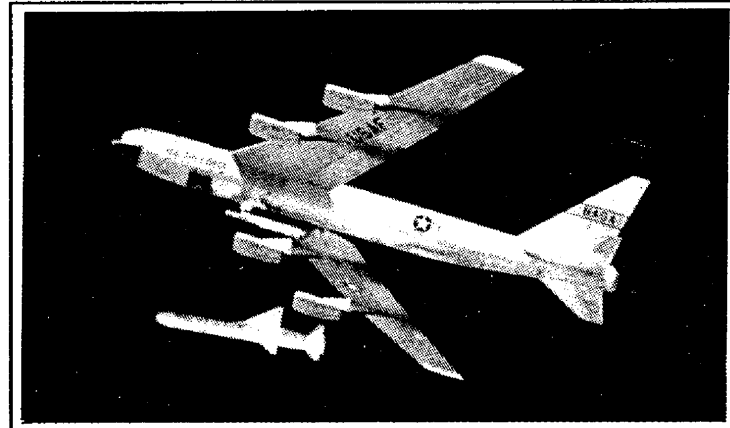
# Pegasus Air Launched Space Booster Flight Operations

Orbital  
Sciences  
Corporation  
**Space Systems Division**

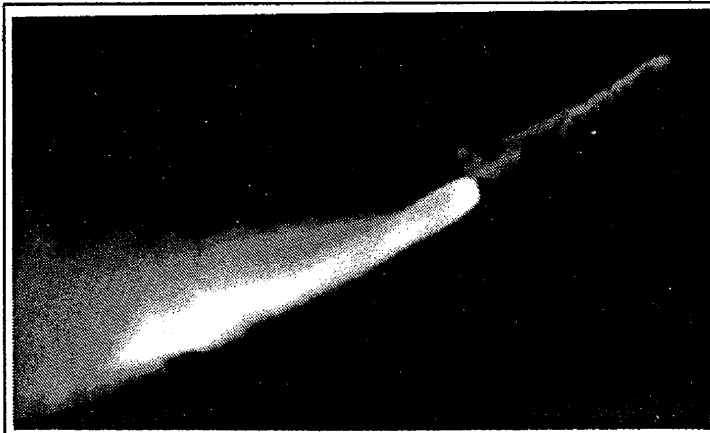
Pegasus In Captive Carry Flight



Pegasus Drop



Pegasus F1 Launch



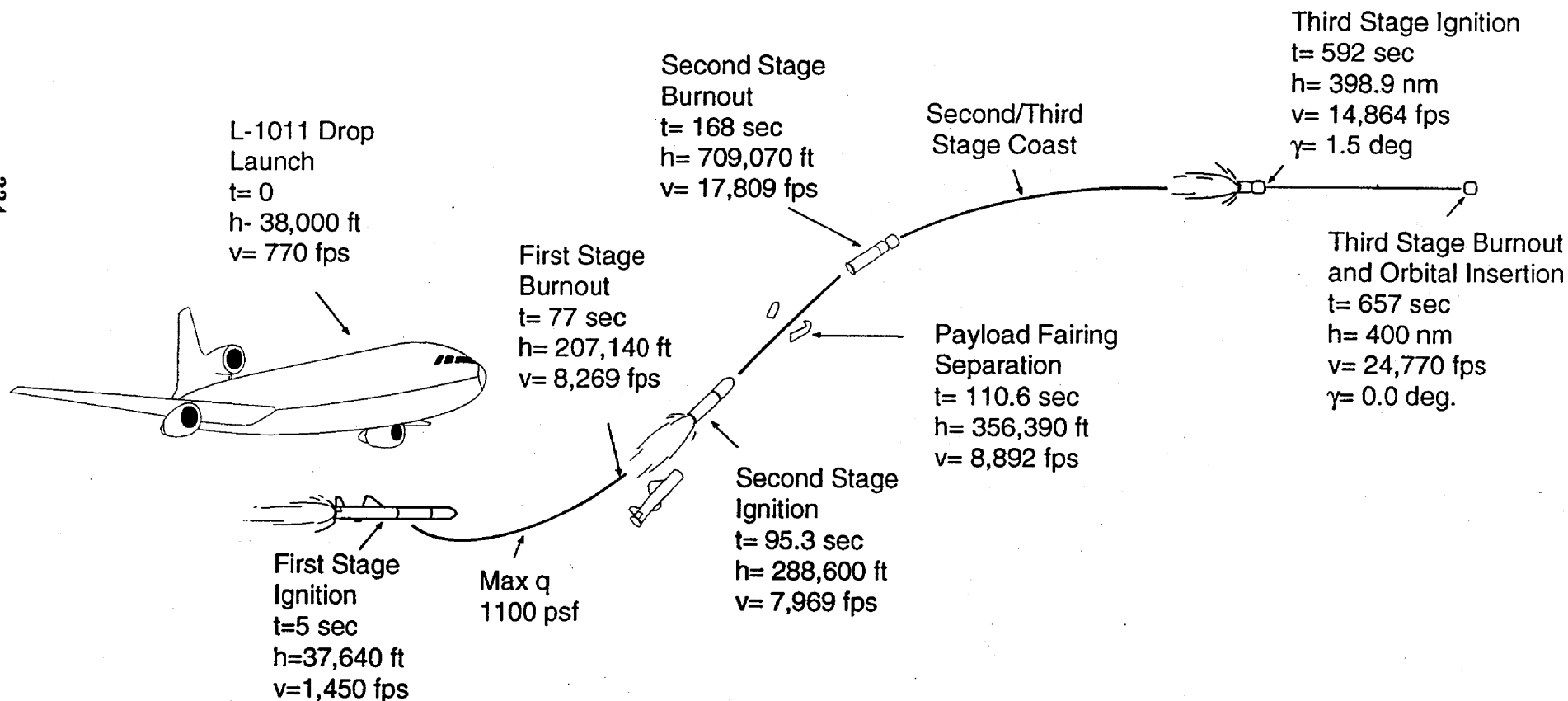
Summary

- Accomplished Highly Successful 1st Flight
  - Demonstrated Ability to Drop on Time and at Desired Location
  - Proved Structural Design
  - Validated Guidance and Control System
  - Confirmed Techniques for Aerodynamic and Thermodynamic Analysis
  - Demonstrated Benign Payload Environment
  - Launched 2 Satellites into Functional Orbits
  - Obtained Excellent Data from NASA's Aerothermal Experiment

# Pegasus Baseline Mission Profile (400 nmi Trajectory)



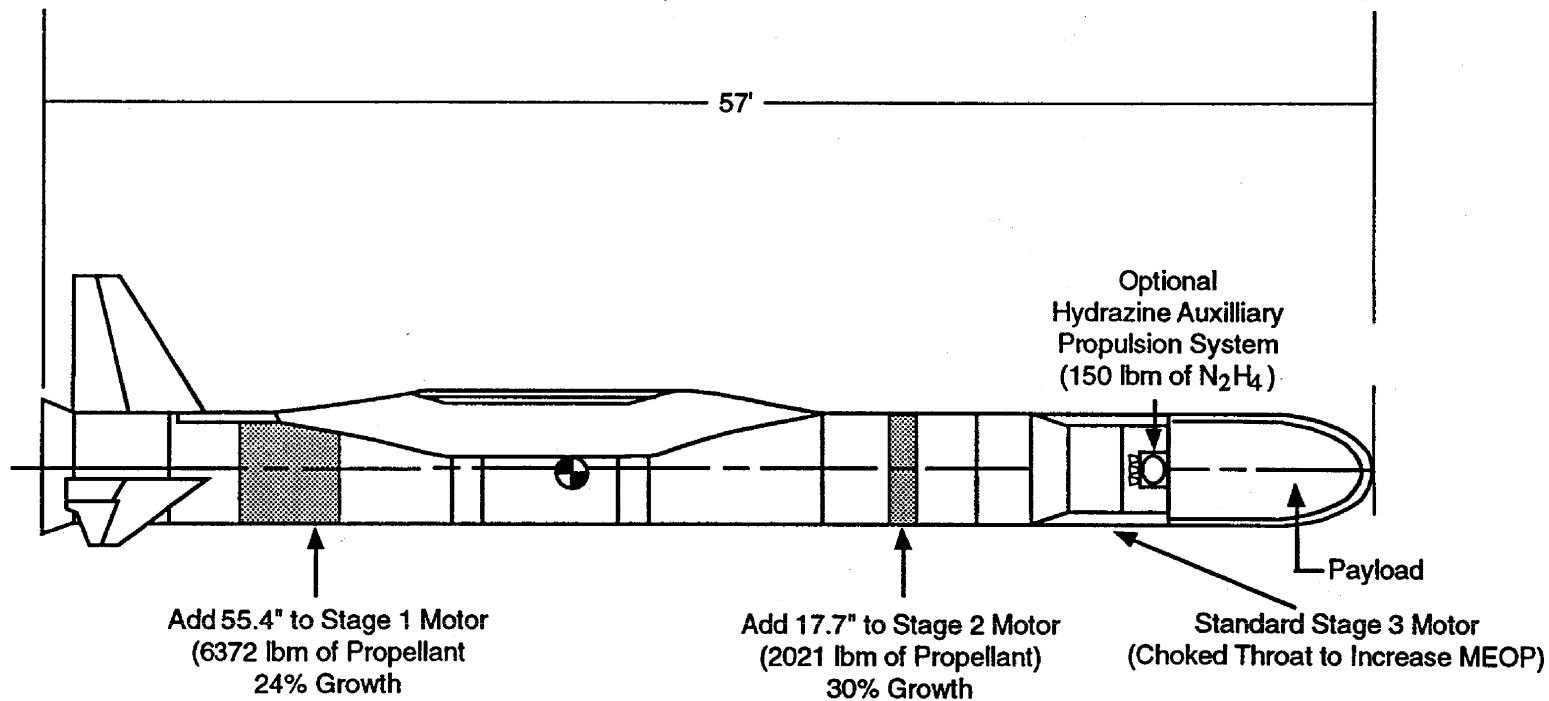
224





# Pegasus XL Configuration

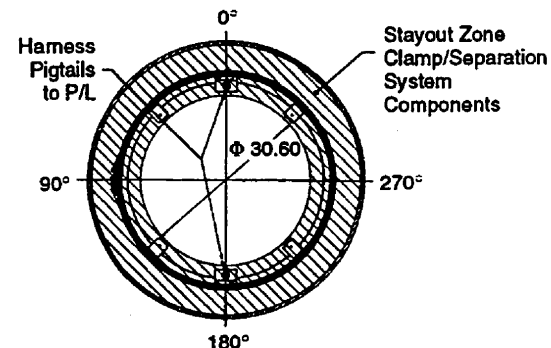
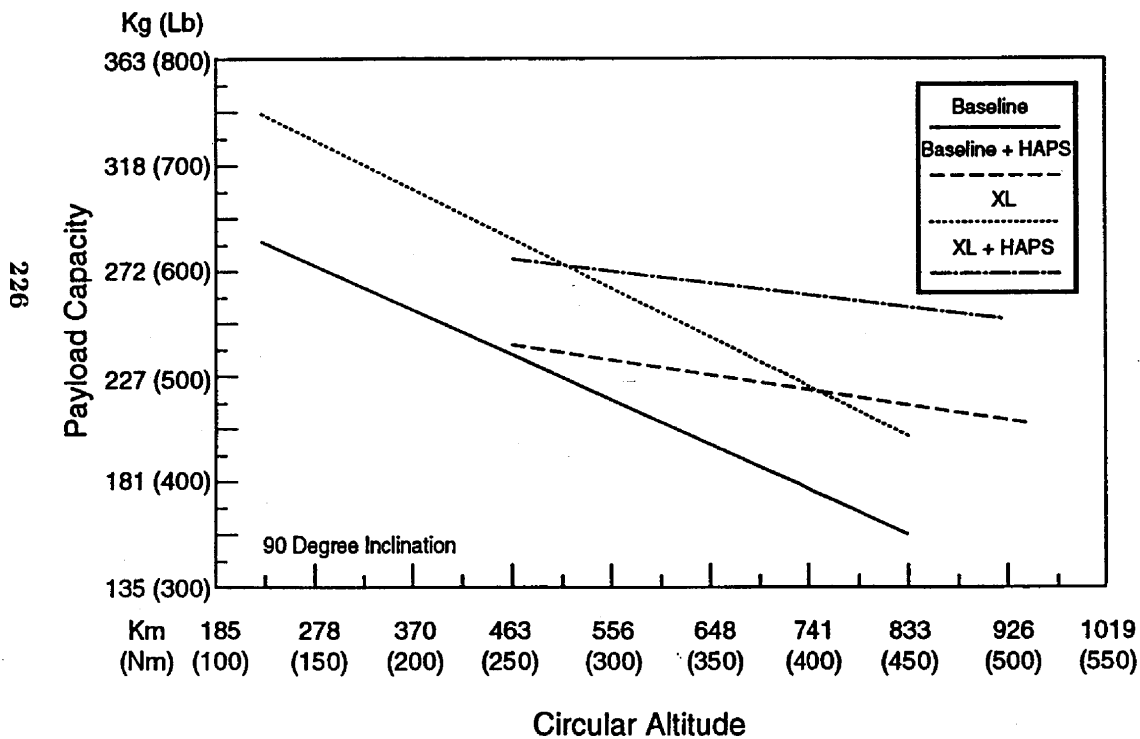
Orbital  
Sciences  
Corporation



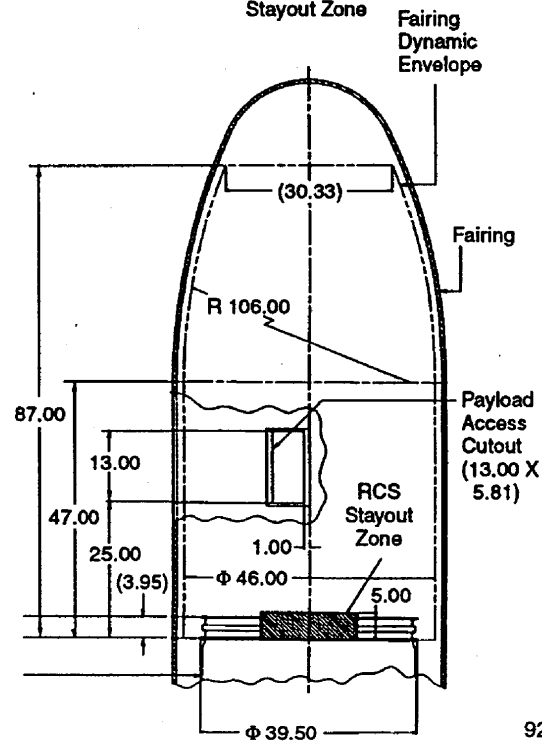
	Propellant Weight (lbm)	Inert Weight (lbm)	Total (lbm)
Stage 1	33,181	4,644.0	37,825.0
Stage 2	8,629	957.0	9,586.0
Payload Fairing		279.0	279.0
Stage 3	1,709	388.5	2,097.5
		Total	49,787.5

# Pegasus Payload Capability and Interfaces

Orbital  
Sciences  
Corporation  
**OSC**  
*Space Systems Division*



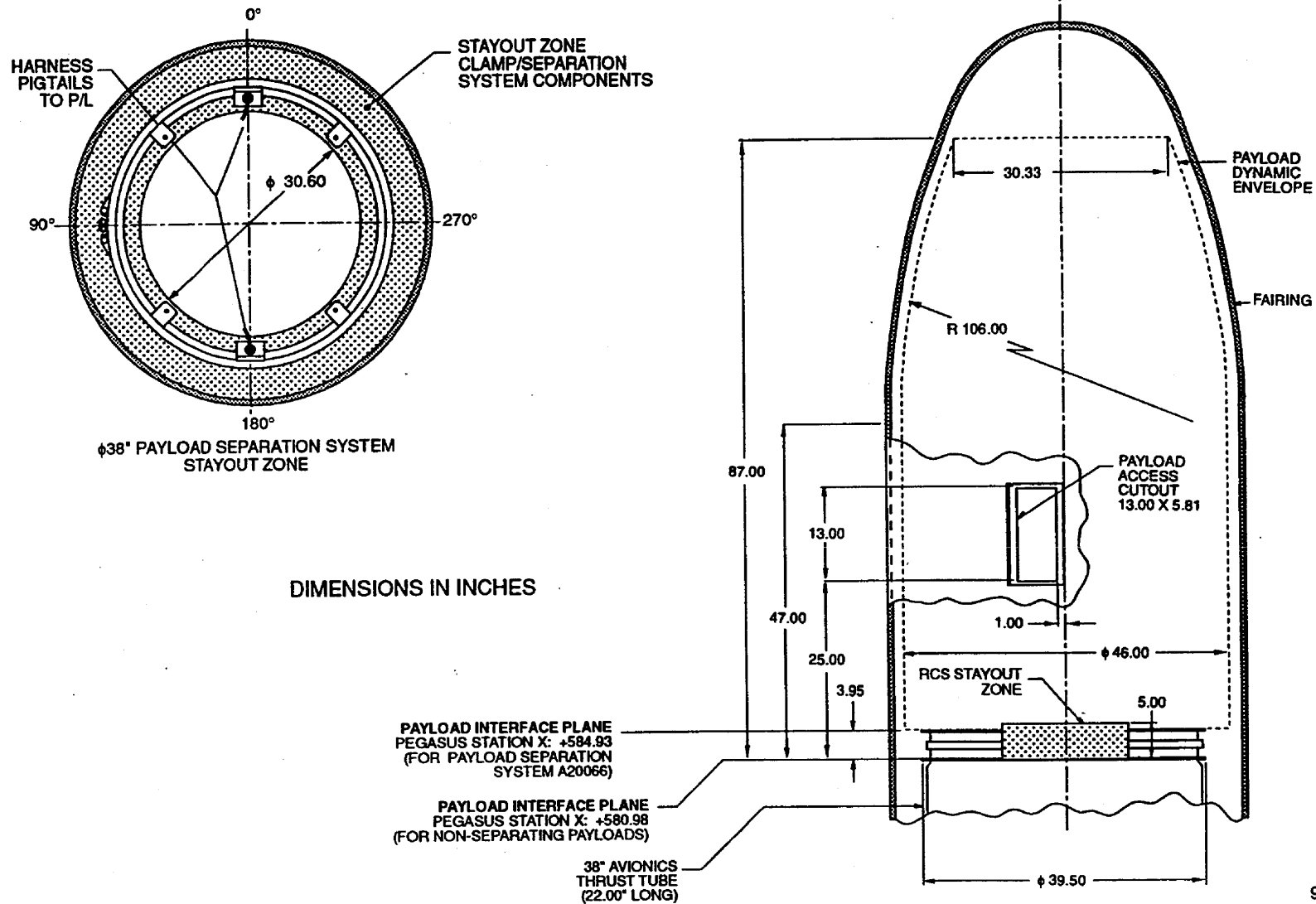
$\Phi 38$  Payload Separation System Stayout Zone



921015.13a

# Payload Fairing Dynamic Envelope with 38" Diameter Payload Interface

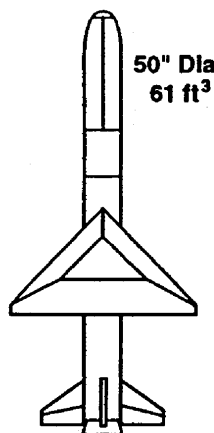
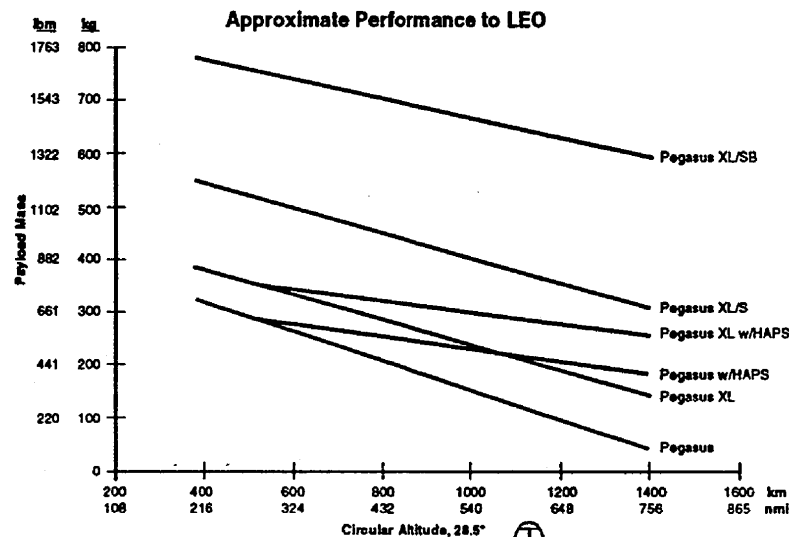
Orbital  
Sciences  
Corporation



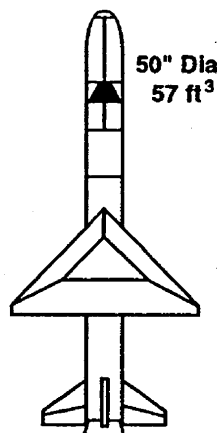
920720.28b

# Pegasus Launch Vehicle Configurations (Evolutionary Path)

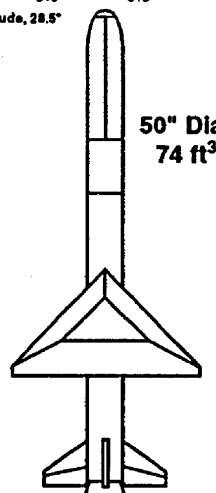
Orbital  
Sciences  
Corporation



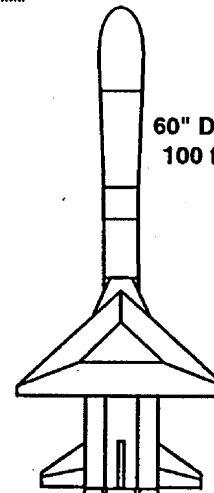
**Pegasus  
(F1 Vehicle)**



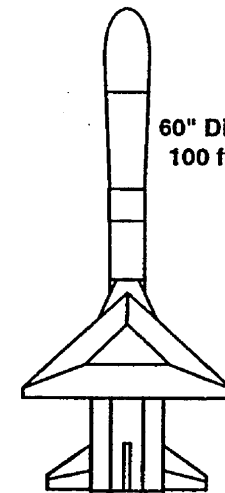
**Pegasus  
w/ HAPS  
(F2 Vehicle)**



**Pegasus XL  
(In Development)**



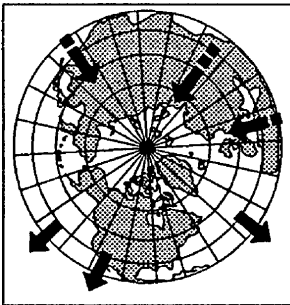
**Pegasus XL/S  
(Proposed)**



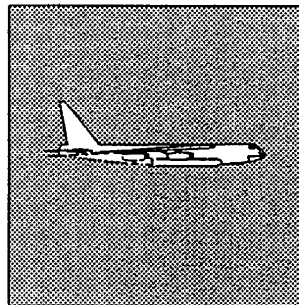
**Pegasus XL/SB  
(Proposed)**

## Operational Flexibility

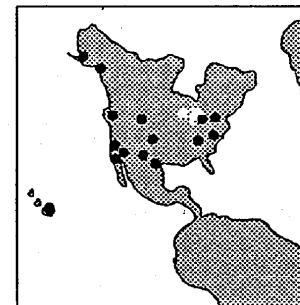
Orbital  
Sciences  
Corporation  
**Osc**  
*Space Systems Division*



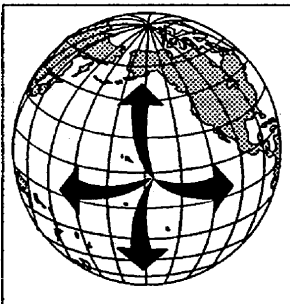
**First Pass Coverage of Any Point on Earth**  
(Surveillance, R.F. Relay, Ordnance Targeting)



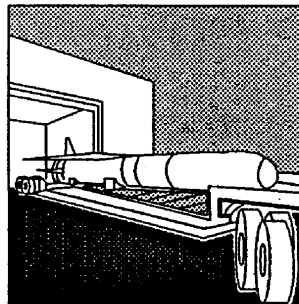
**Complete Launch Preparation and Operations Security**  
(No Pad Operations, Flexible Launch Point)



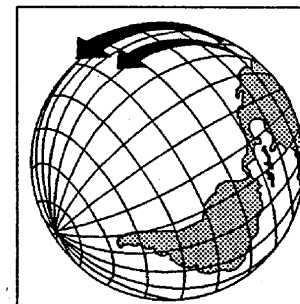
**High System Survivability**  
(Transportable GSE, Over 200 Suitable Military Aircraft and Numerous Airfields Worldwide)



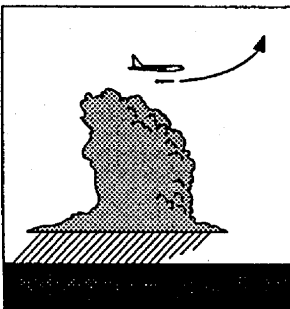
**Omni-Inclination Launch**  
(Mission Flexibility, Eliminates Doglegs, Performance Improvement)



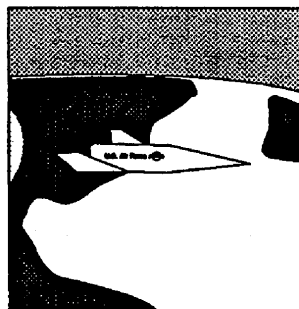
**Rapid Call-Up and Quick Turnaround**  
(Ordnance-Style Integration and Vehicle Handling)



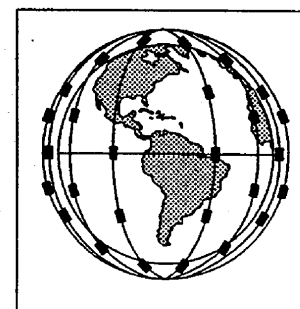
**Retrograde Orbits/ "Passing Shot" Missions**  
(SDIO Targets, BSD Tests)



**Reduced Weather Constraints on Launch**  
(Fly Above or Around Weather)



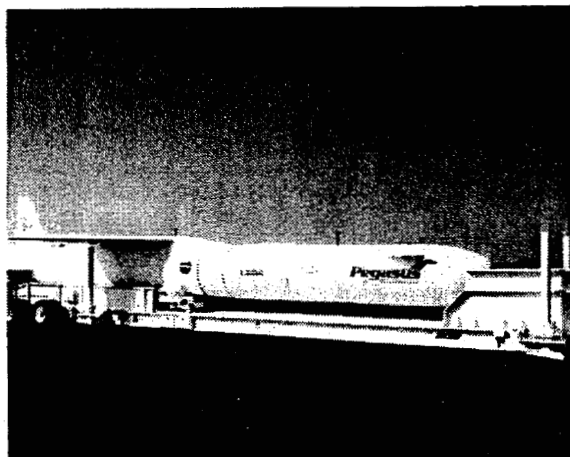
**Hypervelocity Missions**  
(Hypervelocity Vehicles)



**High Sustained Launch Rates to Create or Restore Constellations**  
(Several Launches/Day/Aircraft, No Launch Pad Refurbishment)

# Pegasus Air Launched Space Booster Operational Features

Orbital  
Sciences  
Corporation  
**Space Systems Division**



**Rapid Call-Up  
and Quick  
Turnaround  
(Ordnance-  
Style Integra-  
tion and Vehicle  
Handling)**

## Operational Response Capability

### A. No Prior Alert (Unlimited Shelf Life)

- Pre-Assembled Stage Integration Completed
- Prepositioned Payload Mated to S3 Interface
- Pre-Activated Batteries

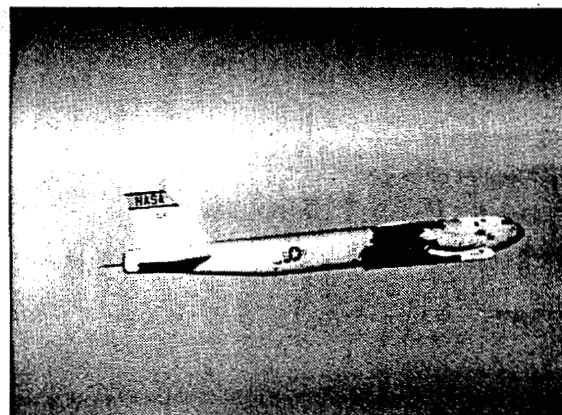
Unpacking, Subsystems Check, Battery and N <sub>2</sub> Top-Off:	8 Hrs	Trajectory Preparation:	4 Hrs
System-Level Checks:	2 Hrs	Payload Checks	4 Hrs
Fairing Installation and Vehicle Close-Out:	4 Hrs		
Carrier Aircraft Mating:	2 Hrs		
Flight to Launch Zone:	1-3 Hrs		
<b>Total Time to Orbit:</b>	<b>17-19 Hrs</b>		

## Operational Response Capability

### B. On Readiness Alert (6 Week Shelf Life)

- Fully Assembled and Checked Vehicle,  
Payload
- Batteries on Trickle Charge

N <sub>2</sub> Top-Off and System-Level Check:	2 Hrs
Carrier Aircraft Mating:	2 Hrs
Flight to Launch Zone:	1-3 Hrs
<b>Total Time to Orbit:</b>	<b>5-7 Hrs</b>



**Complete  
Launch Prepa-  
ration and  
Operations  
Security  
(No Pad Opera-  
tions, Flexible  
Launch Point)**

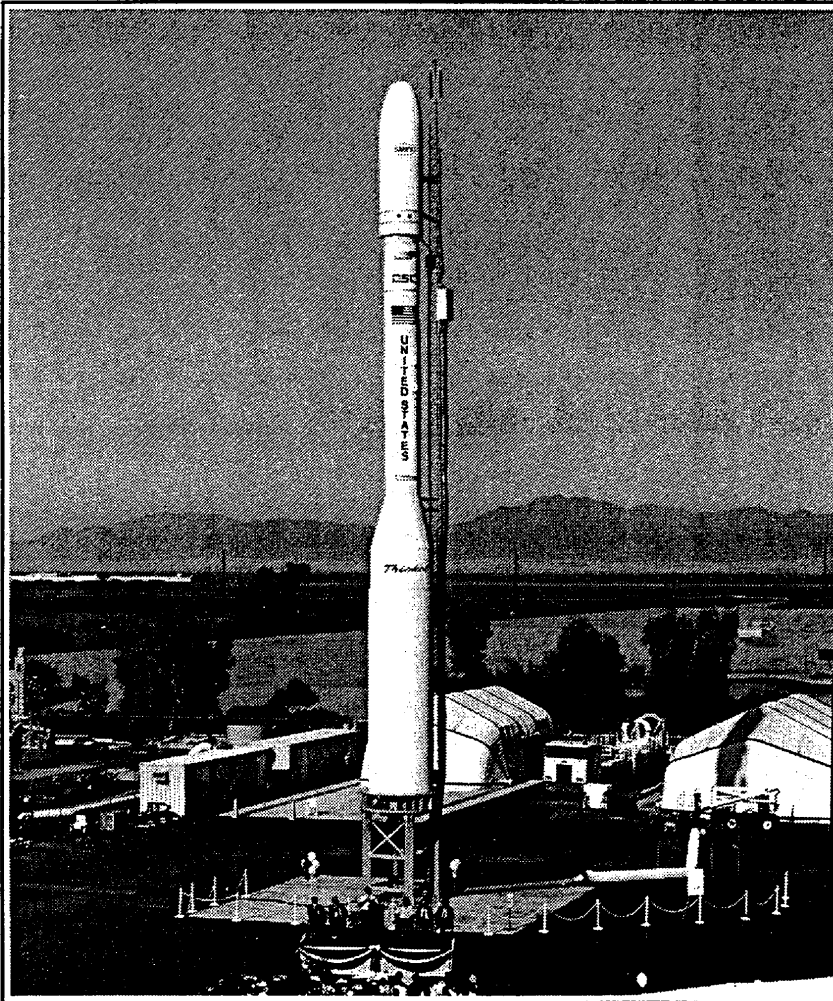


Orbital  
Sciences  
Corporation



## Taurus® Launch Vehicle

Orbital  
Sciences  
Corporation




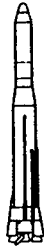
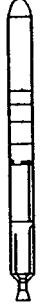
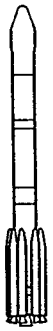
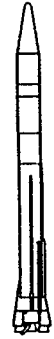

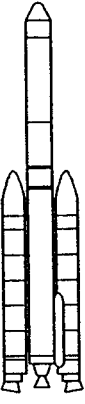
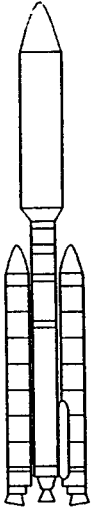
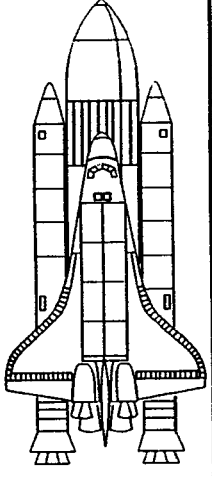


- Four-Stage, Inertially-Guided, 3-Axis Stabilized, Solid Propellant Launch Vehicle
- Capabilities
  - Up to 1400 kg (3000 lbm) to LEO
  - Ground Launched
  - Compatible with ETR and WTR
  - Road Transportable or Fixed Gantry
  - Rapid Launch Site Establishment (5 Day Goal)
  - Rapid Launch Call-Up (72 Hours from P/L Delivery to Launch)
  - Dry Pad
- Configuration Derived from Pegasus and Other Proven Launch Vehicles
- First Launch Scheduled for Late 1993 from Vandenberg AFB
- Two Firm and 8 Optional Launches Under Contract to DARPA and SDIO



## National Launch Vehicles



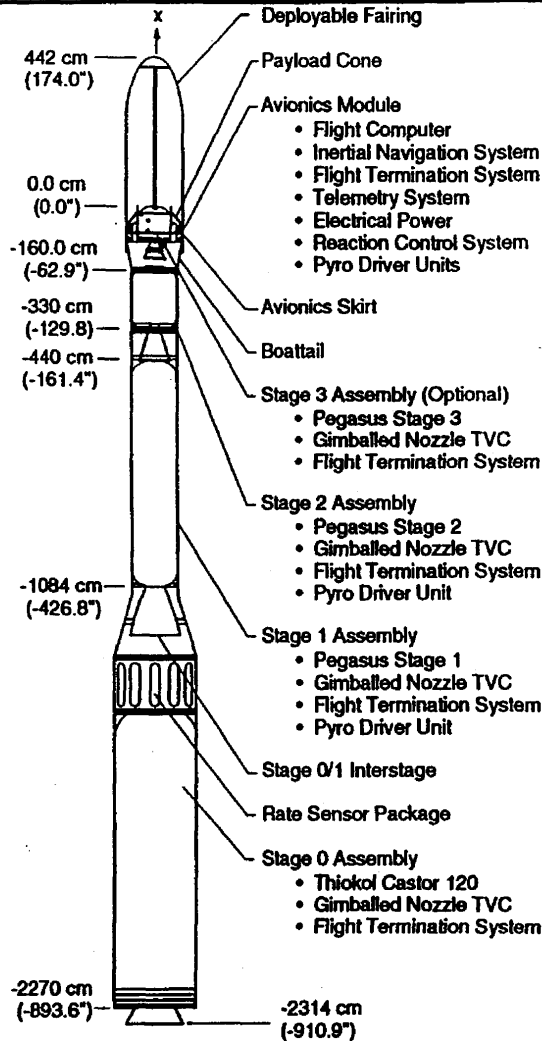
											
	SCOUT	PEGASUS	TAURUS	ATLAS-E	TITAN II SLV	DELTA II	ATLAS CENTAUR	ATLAS II	TITAN 34D	TITAN IV (SRMU)	STS
PERFORMANCE											
SYNCH EQ	---	---	550*	---	---	2100*	2650*	3300*	4000	IUS/Centaur 5000/10,000 (5800/12,700)	5000 (IUS)
LOW EARTH POLAR	460	700	2300	1750	4200	---	---	---	27,600	32,000 (38,600)	---
LOW EARTH DUE EAST	570	950	3000	---	---	11,100	12,300	14,300	32,900	39,000 (47,000)	51,000

Adapted from Aerospace Corporation Data

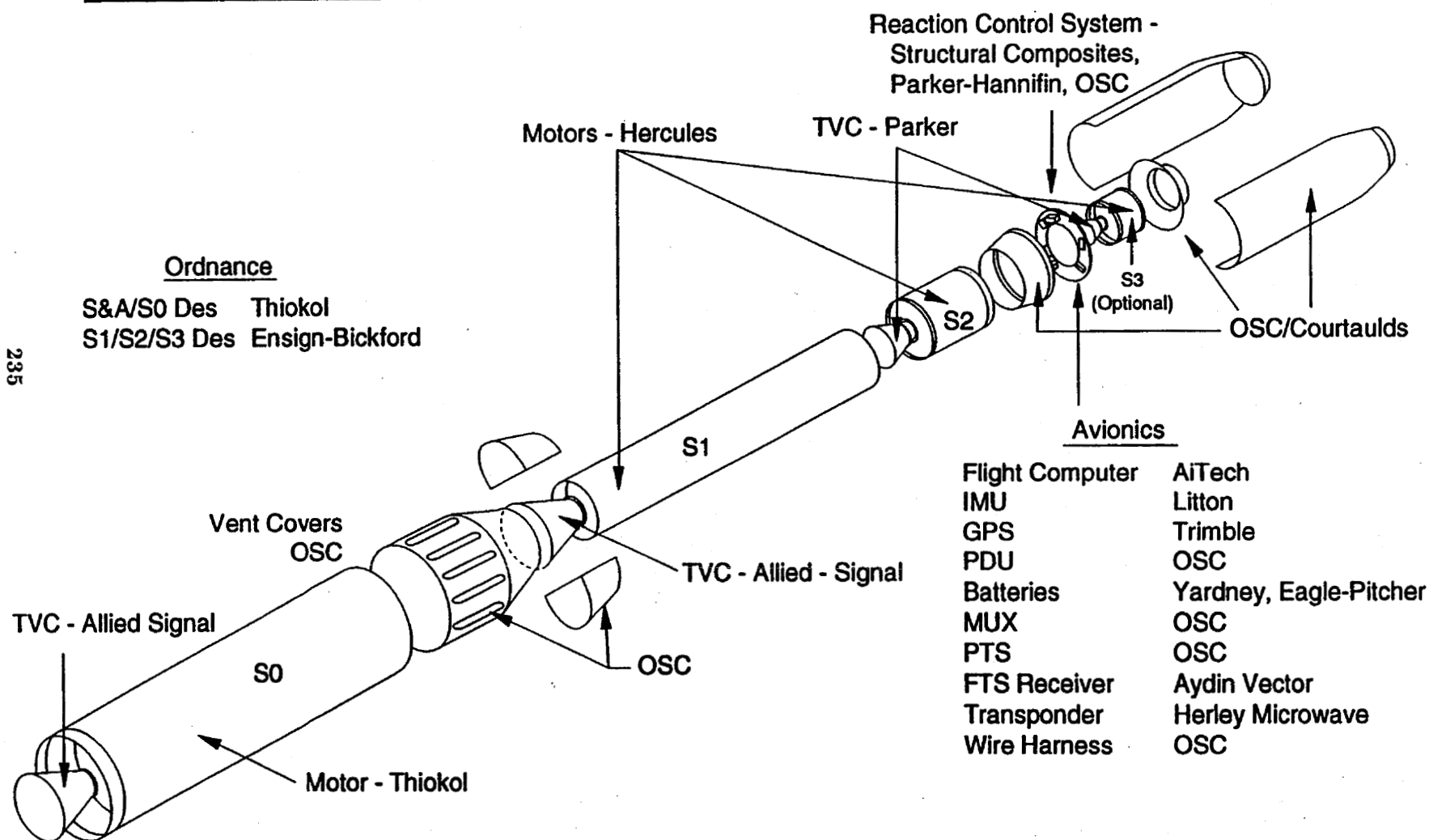
\*AKM Required

80812.23 I

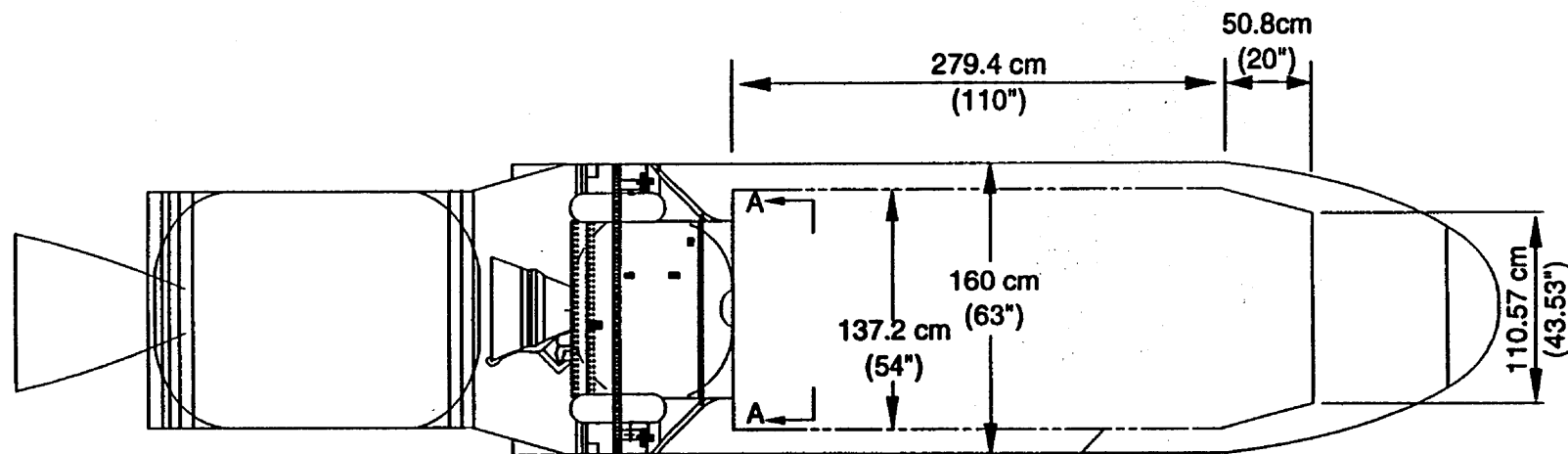
# Taurus Vehicle Configuration



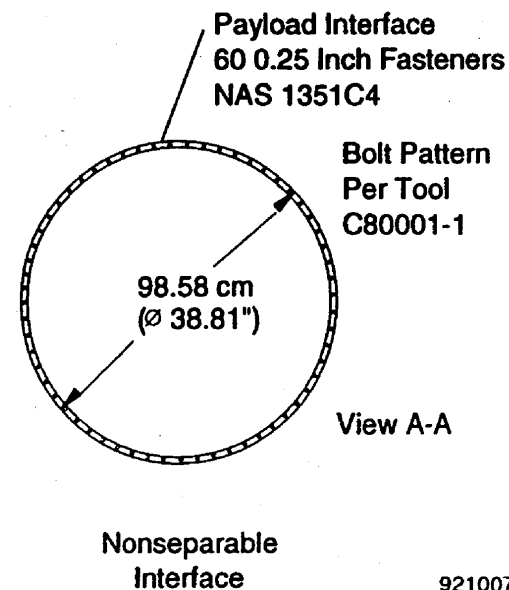
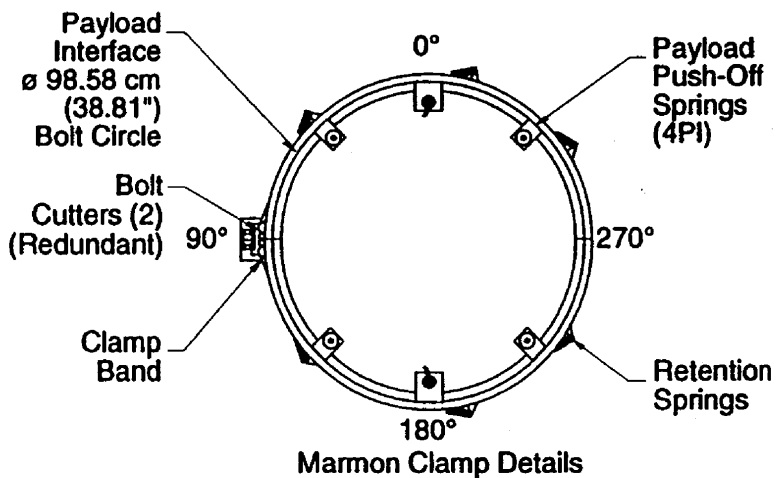
# Taurus Stage Buildup



# Taurus Mechanical Interfaces



Payload Dynamic Envelope



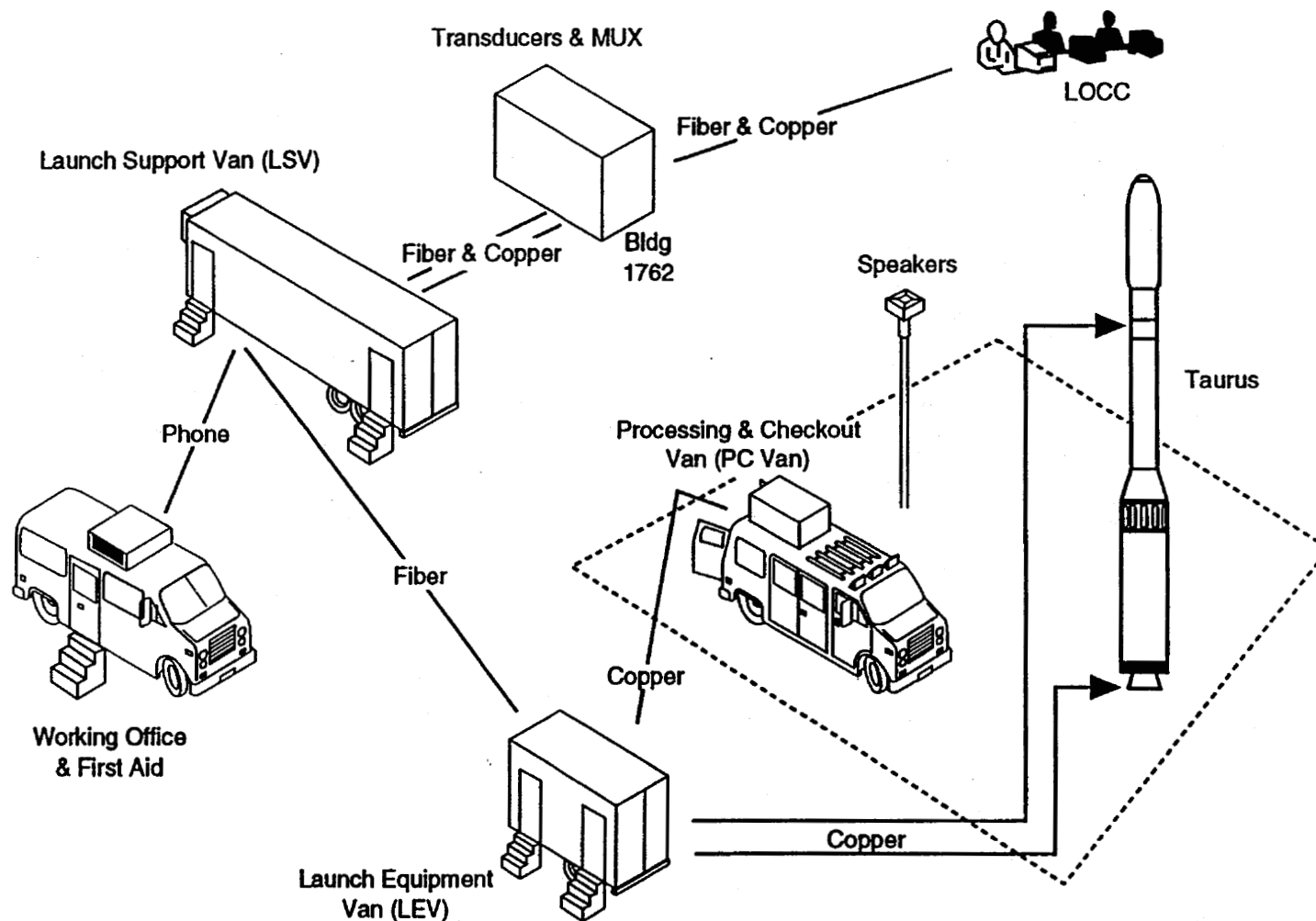
921007.18

## **Taurus Launch Capabilities**

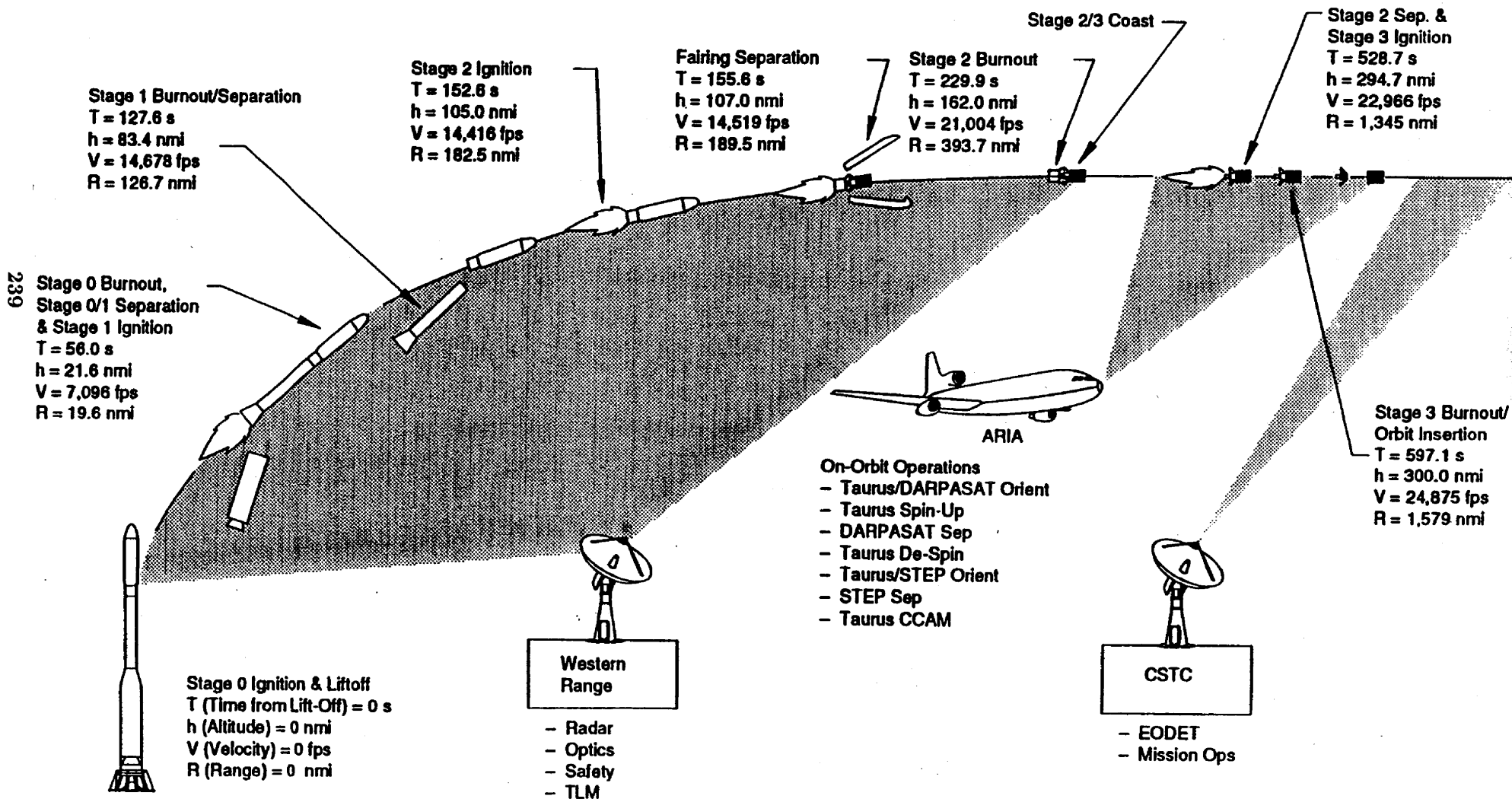


- **Taurus Design Incorporates Transportable LSE (No Fixed Site Required) and Rapid Launch Capability (Eight Days From Arrival to Launch)**
  - Only Concrete Pad is Needed to Launch From Any Site
  - Twelve Launches/Year Easily Accomodated
- **West Coast Launches**
  - Taurus First Launch Site (576 on NVAFB) Available
  - Potential SVAFB Sites Exist Which Provide Better Launch Azimuth to Posigrade Orbits
- **East Coast Launches**
  - OSC Part of Spaceport Florida Team Which Was Awarded \$2.15M Grant to Develop Small Launch Vehicle Site at CCAFS
    - Modification of LC-46 In Progress to Support Launch of Castor 120-Based Vehicles
    - Site Will be Complete for Taurus BMDO Launch in Early 1995
  - Can Use Transportable LSE to Launch From CCAFS Before Gantry Availability
  - OSC Has Also Pursued Launching Taurus From WFF Using Transportable LSE

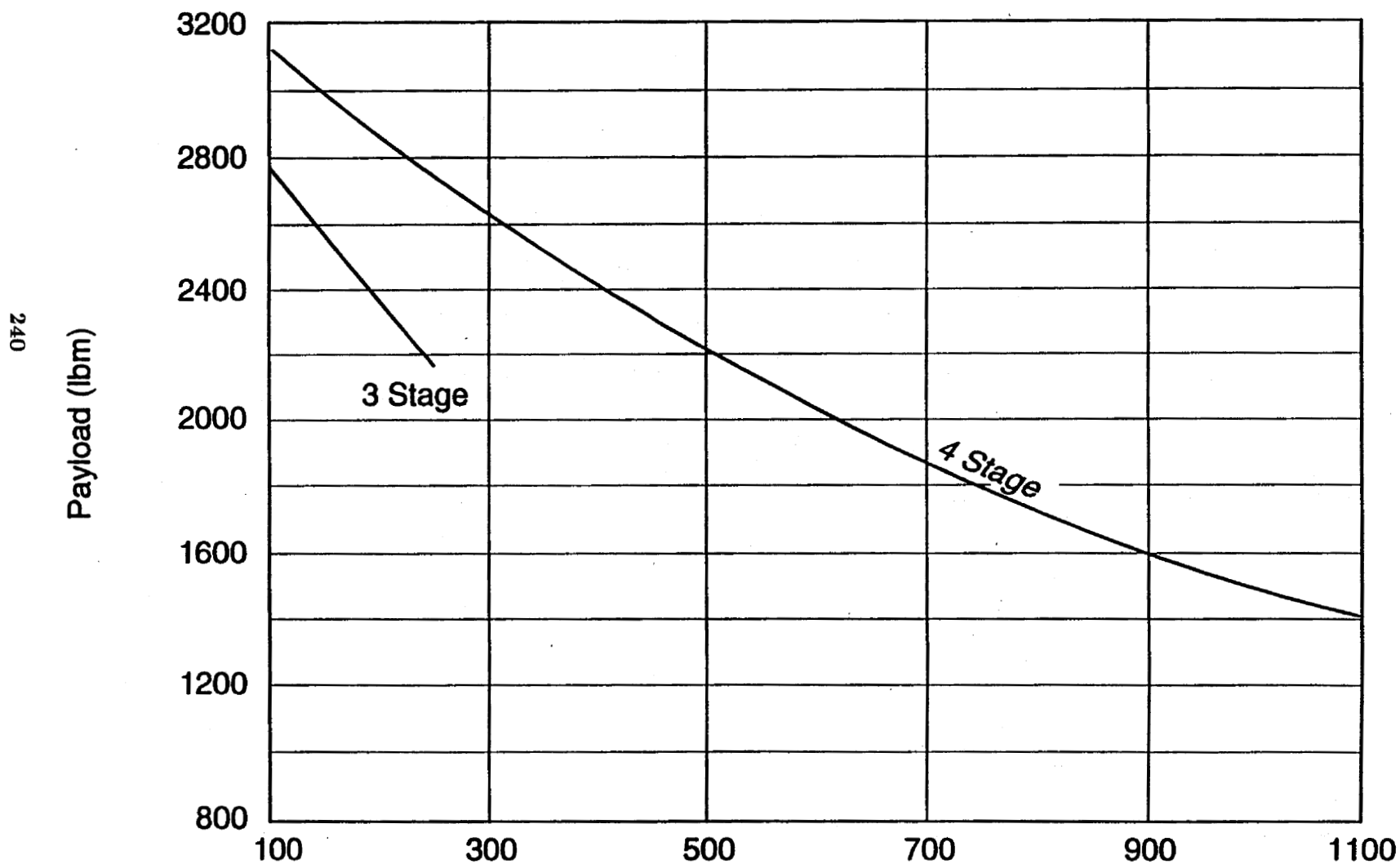
# Taurus Launch Support Equipment



# Flight Operations



## Taurus LEO Performance Map to 28.5° From CCAFS



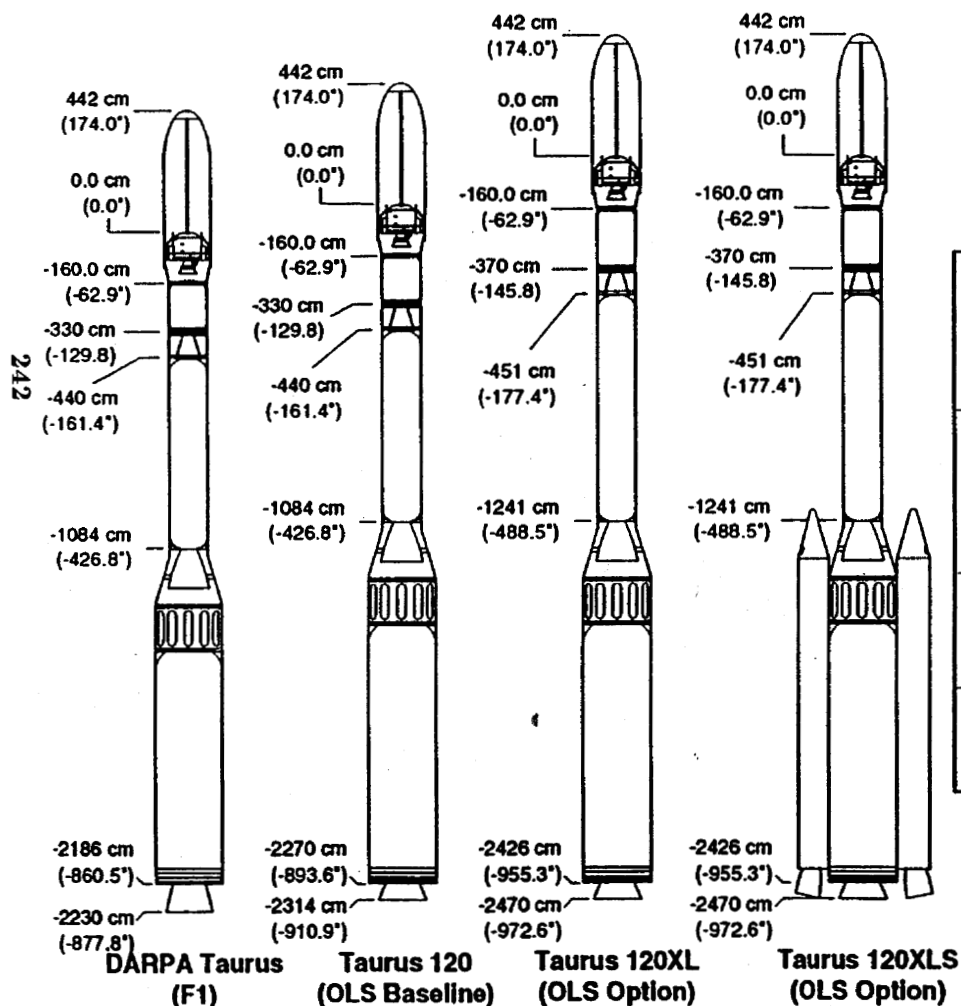


## Demonstration Launch Status



- Taurus Initial Launch Capability Scheduled for November, 1993 from Site 576E on Vandenberg Air Force Base (VAFB)
- OSC Has Completed Three Pathfinder Activities in Our Chandler, AZ Facility and One at Our VAFB Launch Site
  - Full-Scale Inert Vehicle with Functional Electronics
  - Validated All Vehicle Interfaces and Integration Procedures
  - Demonstrated Rapid Site Set-up and Vehicle Integration Capability
- Qualification Testing Proceeding Successfully
  - Completed Full-Scale Stage 0/1, Stage 2/3, and Fairing Separation Tests
  - Conducted Qual and Acceptance Tests of New Structures -- Stage 0/1 Interstage, Boattail and Avionics Skirt (Only Payload Cone and Fairing Remain)
- Flight Vehicle Component Production 90% Complete
  - All Four Stages Delivered to VAFB
  - Stage Build-Up Started August 10
  - Completed Stages Transported to Launch Site October

# Taurus Growth Options



	DARPA Taurus	Taurus 120	Taurus 120XL	Taurus 120XLS
P/L to 250 nm (Orion 38 Stg 3)	2450 lbs (1114 kg)	2750 lbs (1250 kg)	3055 lbs (1389 kg)	3895 lbs (1767 kg)
P/L to GTO (STAR 37 PKM)	860 lbs (391 kg)	985 lbs (448 kg)	1140 lbs (518 kg)	1515 lbs (689 kg)
Status	Production		Development	Study
Availability	Now	1993	1994	1995

## **AUTONOMOUS RENDEZVOUS & DOCKING**

**Michael E. Dobbs**  
**ARD Program Manager**

**Dale Apley**

**Peter Tchoryk**

**Presented at the Small Expendable Launch Vehicle Conference**  
**October 1993**

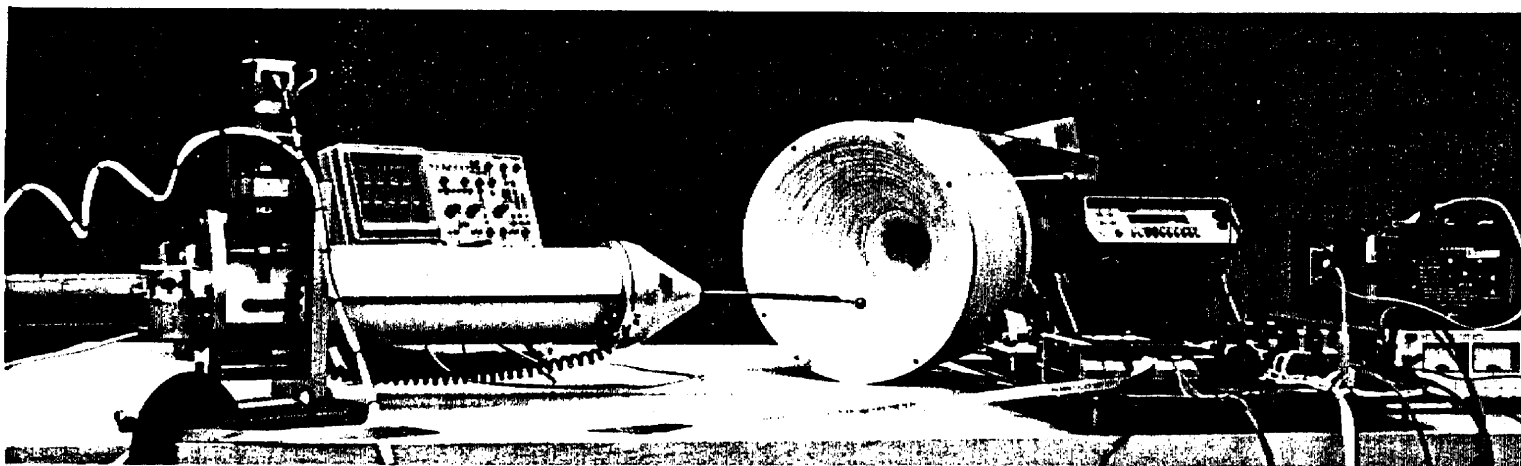
It was necessary to demonstrate, if possible, all aspects of a "servicer" to encourage its acceptance by the user and supplier sectors.

The program was constrained to "cooperative" targets.

---

## Docking Mechanism - First Generation

91-12001.24R1



The ARD-1 payload consists of the following subsystems

- Autonomous experiment controller

- GPS receiver

  - Relative and differential

  - Data link for exchange of GPS navigation data

- Active targets

  - Long range determination of bearing and elevation

  - Short range determination of range and attitude

- Passive targets

  - Short range determination of range and attitude

- Docking system

  - Single point

  - High compliance

- Fluid transfer

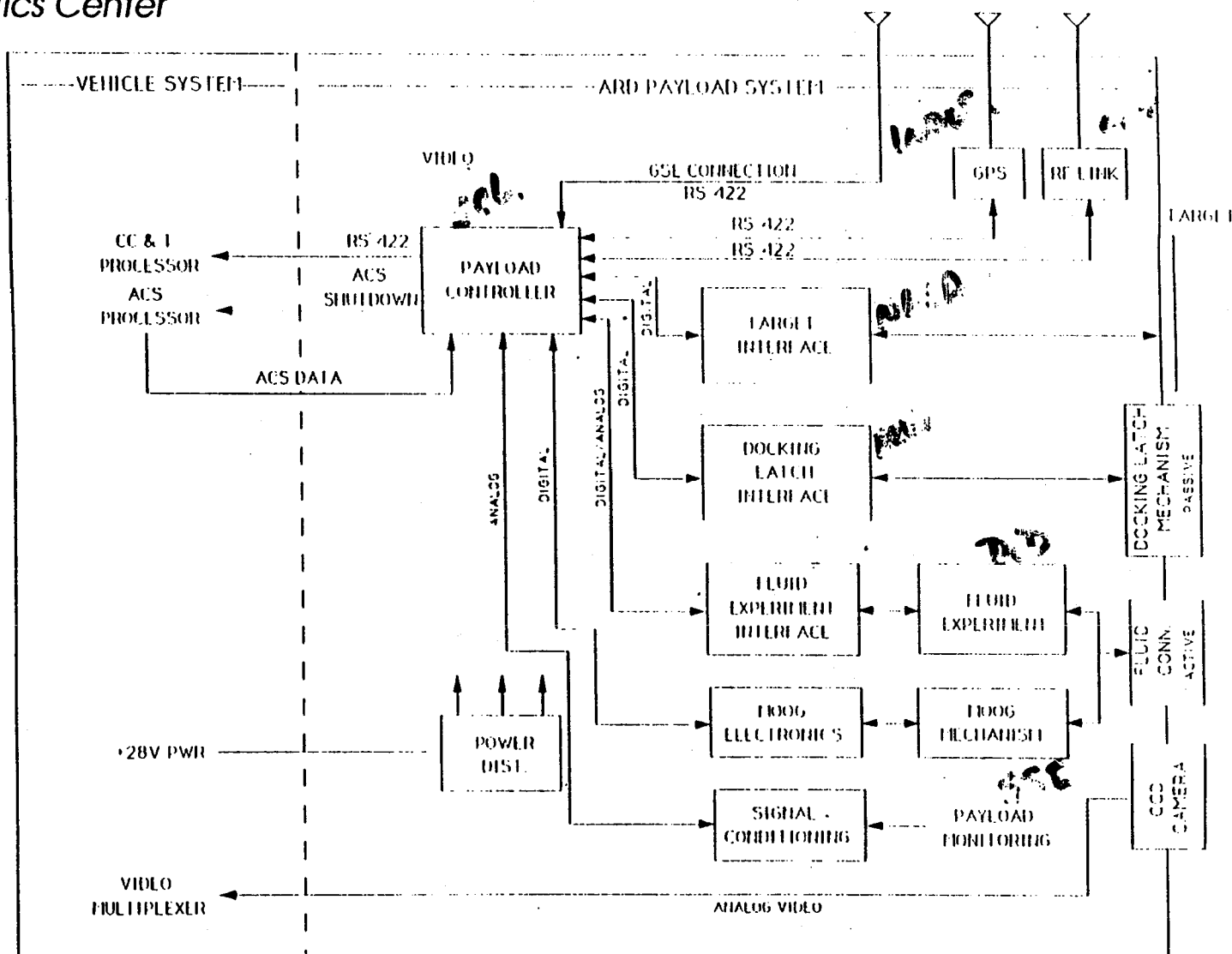
  - Propulsion

  - Process chemistry

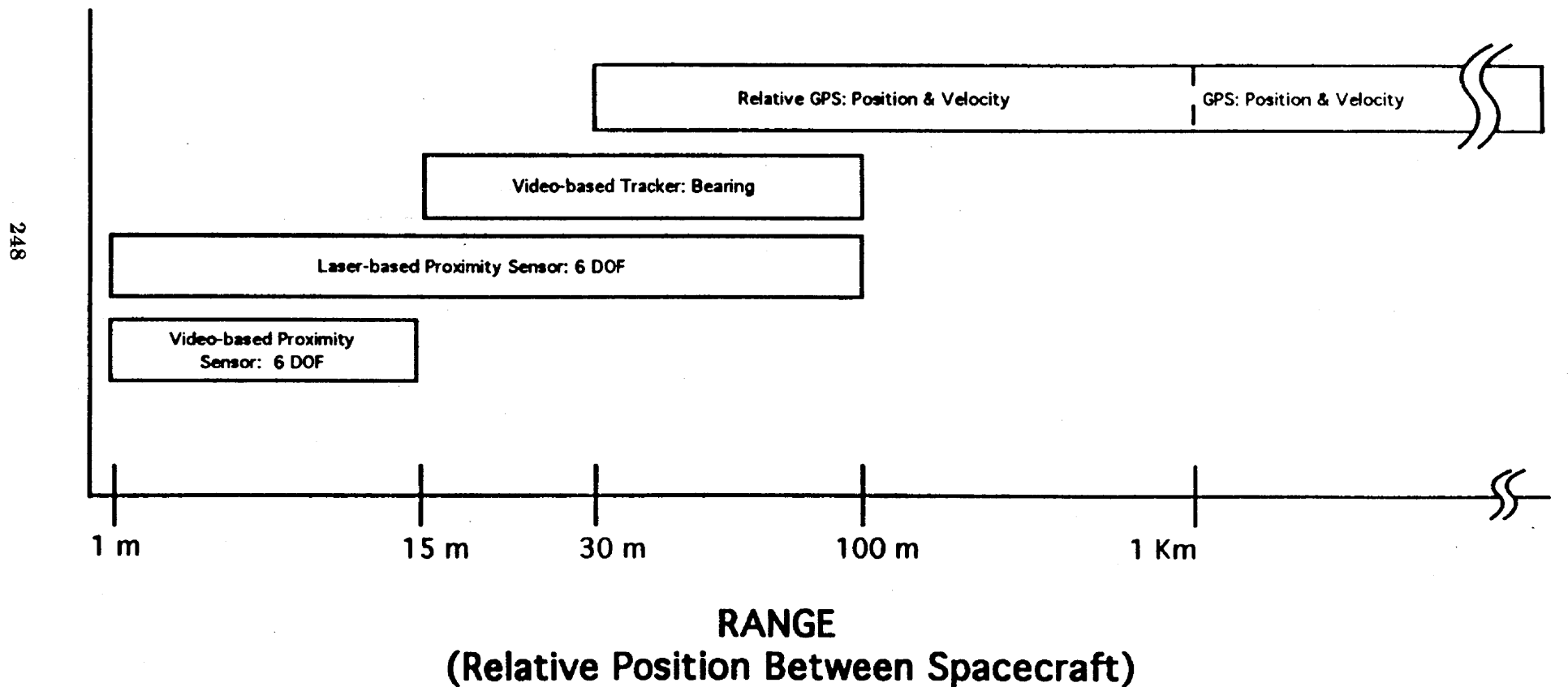
- Payload exchange

  - Recovery of high value materials

# ARD COMET 1 System



# Rendezvous and Proximity Operations: Sensor Data as a Function of Range and Sensor



ENGINEER P. TCHORYK  
SPACE AUTOMATION & ROBOTICS CENTER  
ENVIRONMENTAL RESEARCH INSTITUTE of MI  
ANN ARBOR, MI

DRAFTSMAN S.J. CARR  
Rendezvous & Proximity  
Operations for ARD  
Commit  
011-113

11/11/91
10/17/91
DATE



The ARD-1 Payload was completed on the following schedule:

Conceptual design review - July '91

Critical design review - November '91

Release for fabrication - February '92

Experiment integration and test - June '92

Qualification - September '92

Payload integration - October '92

This was truly a "better, faster, cheaper" program.

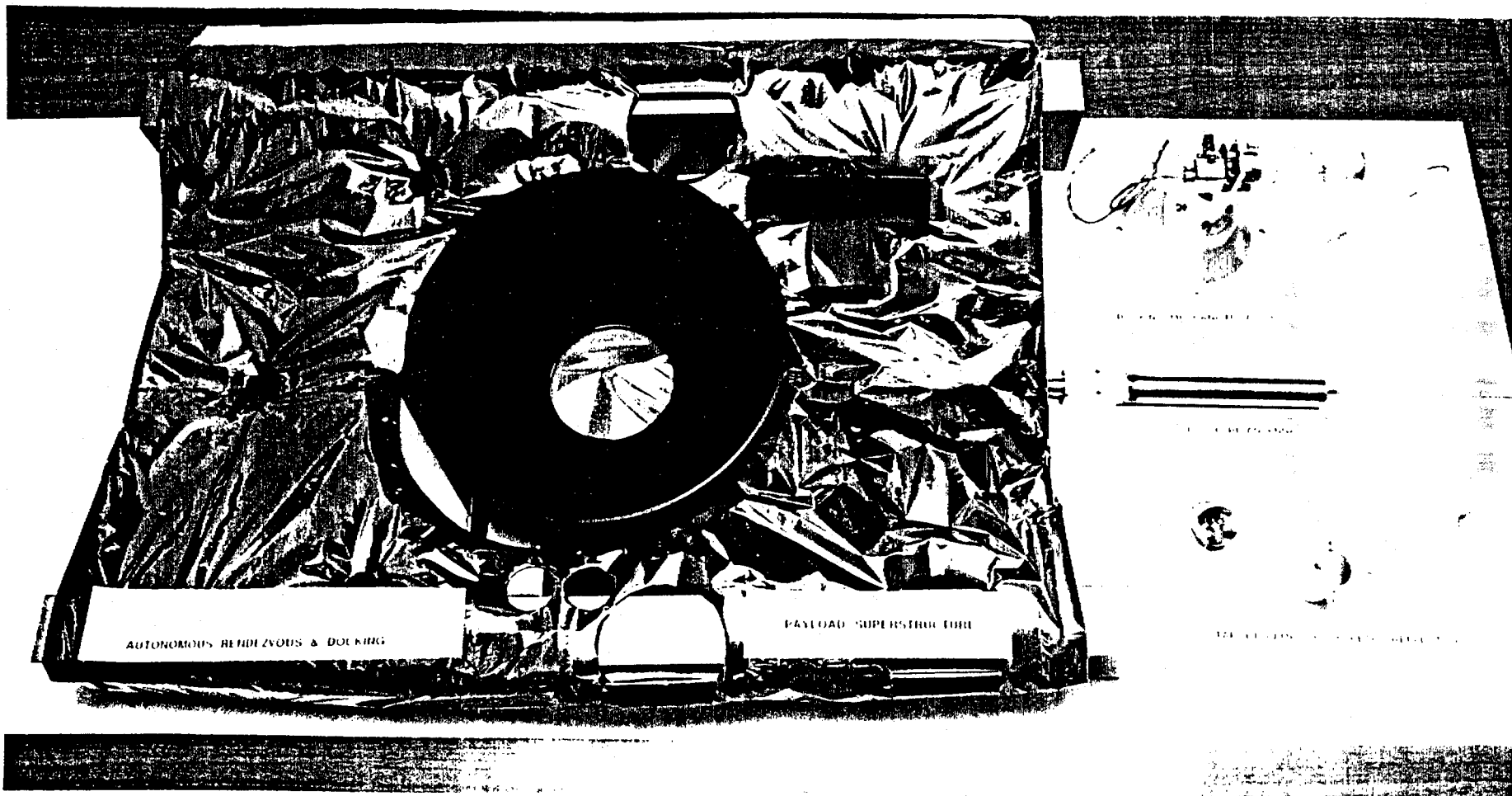
---

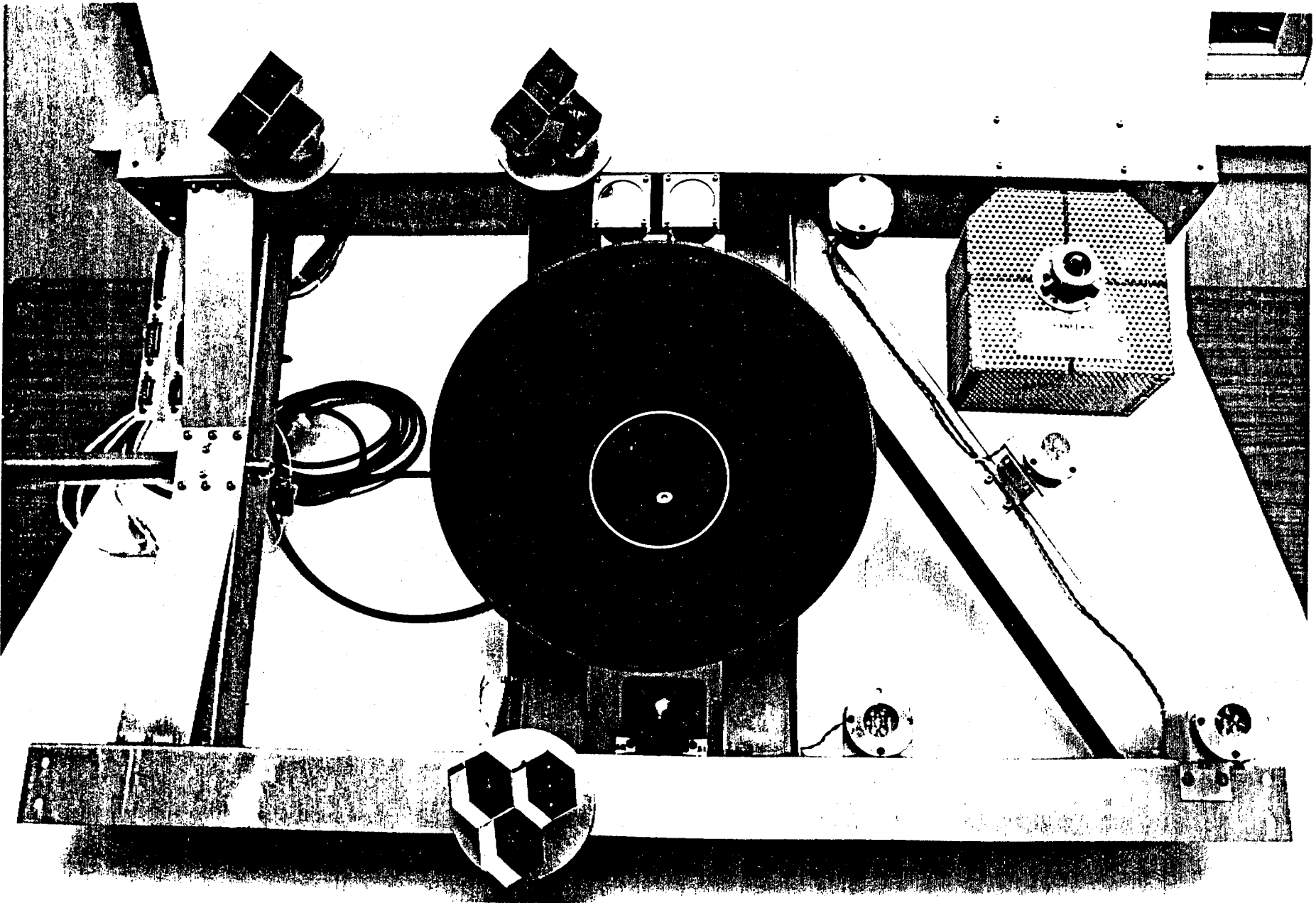
The CCDS Commercial-Off-The-Shelf approach was required to meet budget, schedule and commercialization requirements.

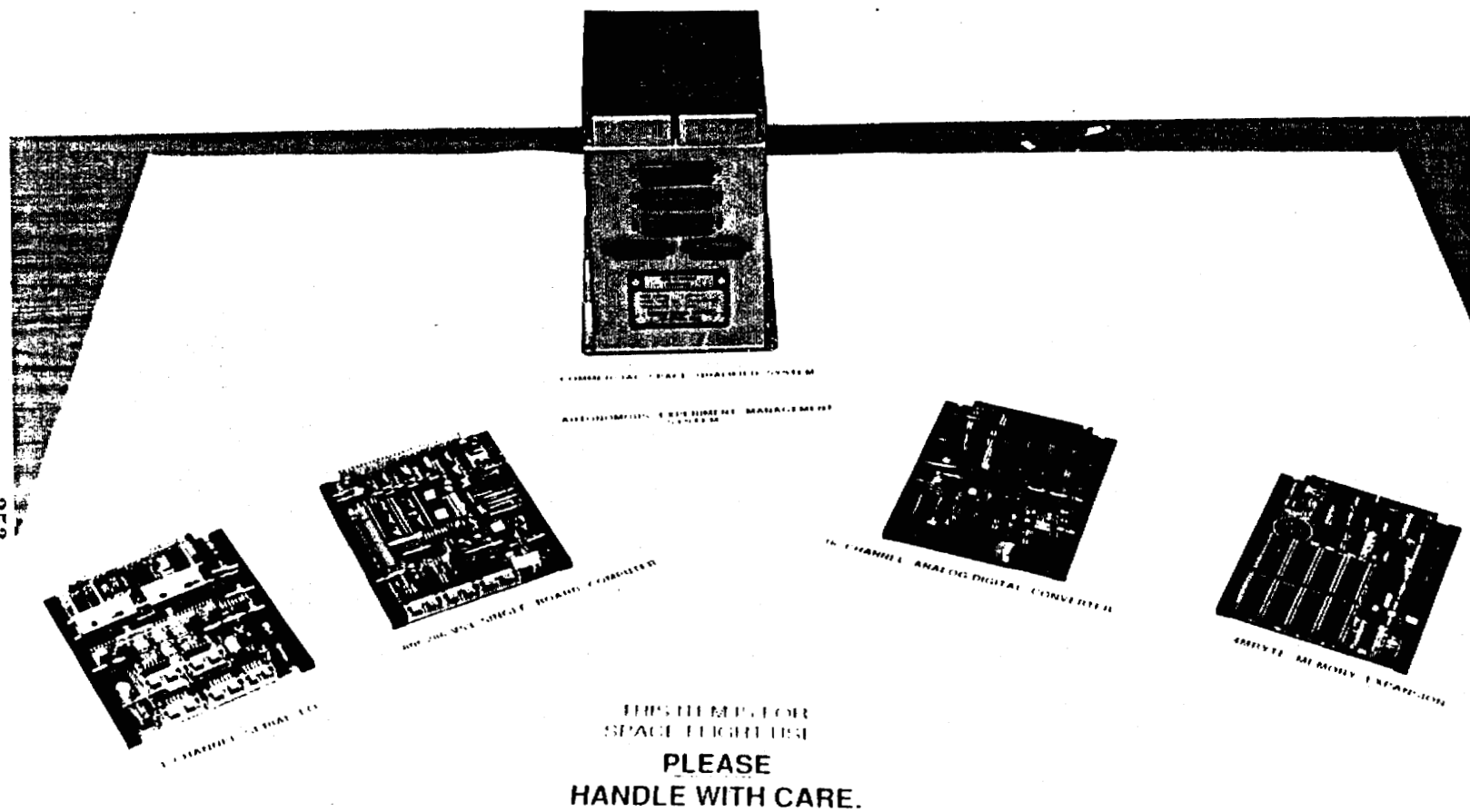
We succeeded in leveraging technology from many agencies:

Naval Research Laboratory  
    Spacecraft Command Language  
    Interface & Control Systems Inc  
Space Station Freedom Program  
    Fluid Quick Disconnect  
    Moog Inc  
MX Program  
    High Pressure N2 Vessels  
    Moog Inc  
Johnson Space Center  
    Passive Machine Vision Targets  
Rockwell  
    Active Machine Vision Targets

---





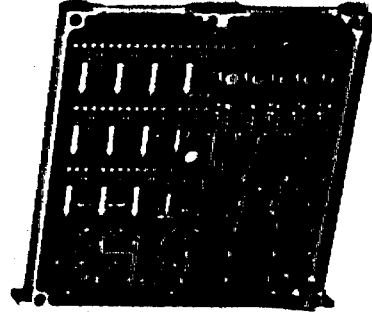


92-11212-26 R1

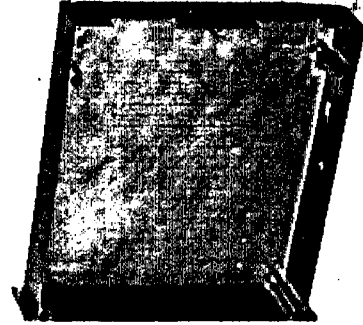


**NASA**  
**SPARC**  
**Autonomous**  
**Rendezvous**  
**And Docking**

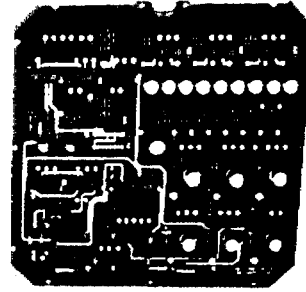
ANALOG MODULE



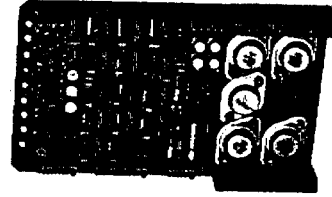
ELECTRONICS HOUSINGS



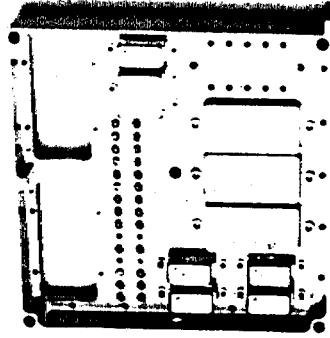
DIGITAL MODULE



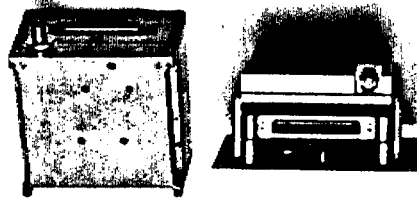
FLUID CONNECTOR CONTROL MODULE



POWER DISTRIBUTION MODULE



GPS RECEIVER MODULE



EARTH POINTED CCD COLOR CAMERA



## **Automation and Robotic Programs**

**Robotic Substrate Servicing System**

NASA Office of Commercial Programs

University of Houston

Wake Shield Facility

Low cost, expendable automation system

Integrated ARD and ORU capability

**Machine Vision for Real Time Process Control**

**Robotic Material Processing System**

NASA Goddard Space Flight Center

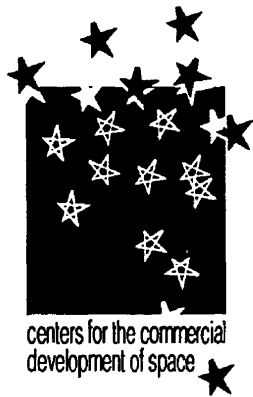
Commercial-off-the-shelf robotic control system

Hitchhiker Program

**Automated Space Production Experiments Network**

NASA Office of Commercial Programs

Low cost, reconfigurable research facility



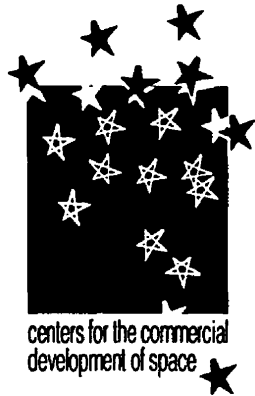
# Mission Statement

---

**Provide a pathway for U.S. Industry to develop commercial markets using the attributes of space**

- New and Improved**
  - Products**
  - Services**
  - Processes**

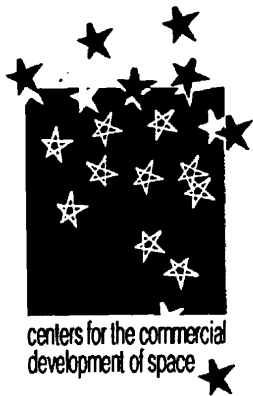




# Overview

---

- **Designed to increase private-sector investment in commercial space-related activities**
- **Joint undertakings involving teams of U.S. industry, university, and other non-NASA government agencies**



# CCDS Concept

91 23403

## Industrial Participants

- Scientific/Technical Direction
- Engineering Talents
- Research/Project Funding



- Interest in Resultant Technical Rights and Proceeds
- Leveraged Resources
- Extended Technical Capabilities

## Government Participants

- Scientific/Technical Support
- Funding
- Space Transportation



- Industrial Base Development
- Generation of Industry-Sponsored Research

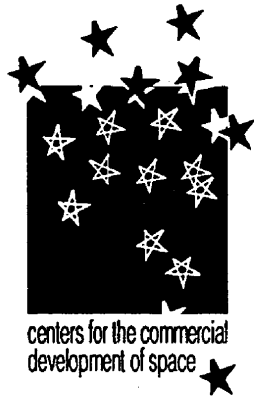
## Academic Participants

- Scientific/Technical Direction
- Funding
- Facilities



- Interest in Resultant Technical Rights and Proceeds
- Professional Development of Faculty and Students
- Extended Research Capabilities

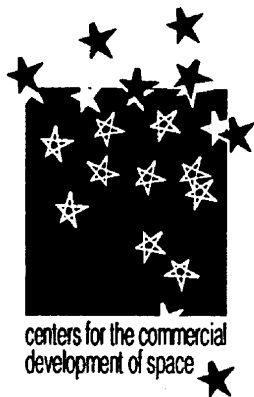
CCDS  
Projects



## CCDS Differences From Other NASA Programs

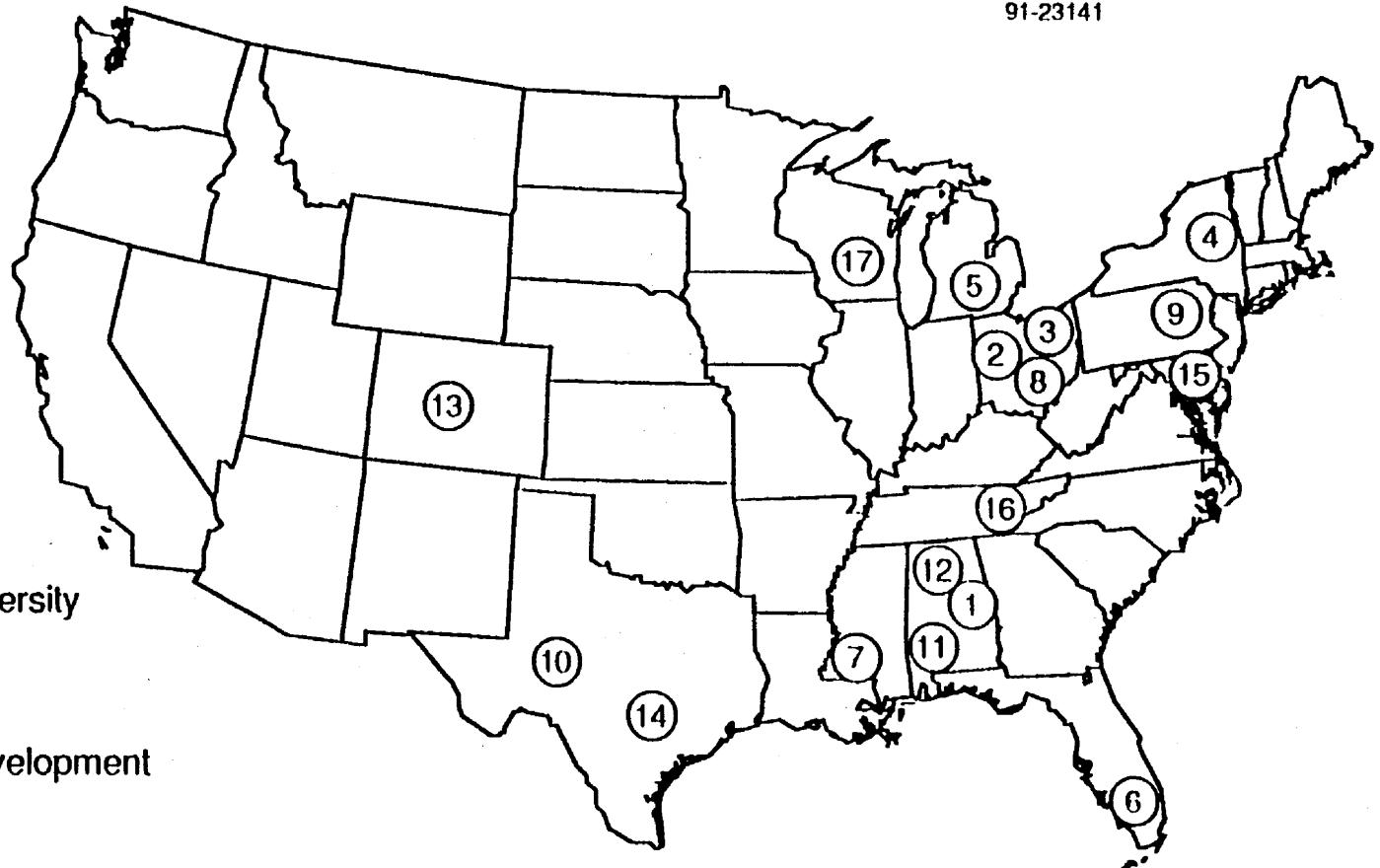
---

- **Identify and develop areas which commercially exploit the attributes of the space environment**
- **Significant private sector capital outlays by "Non-traditional" NASA participants**
- **FY '92 NASA Commercial Programs budget of \$123 million is less than 1% of the total NASA budget**
- **Private sector investment provides a commercial leverage on NASA funds**



# GEOGRAPHIC LOCATION OF CCDS'S

91-23141



260

1. Auburn University
2. Battelle
3. Case Western Reserve University
4. Clarkson University
5. ERIM
6. Florida Atlantic University
7. Institute For Technology Development
8. Ohio State University
9. Penn State University
10. Texas A&M University
11. University of Alabama, Birmingham
12. University of Alabama, Huntsville
13. University of Colorado
14. University of Houston
15. University of Maryland
16. University of Tennessee
17. University of Wisconsin



# CCDS Commercial Focus

---

- **Material Processing**
- **Biomedicine**
- **Remote Sensing**
- **Communications**
- **Infrastructure**
  - **Automation and Robotics**
  - **Space Propulsion**
  - **Space Structure**
  - **Space Power**

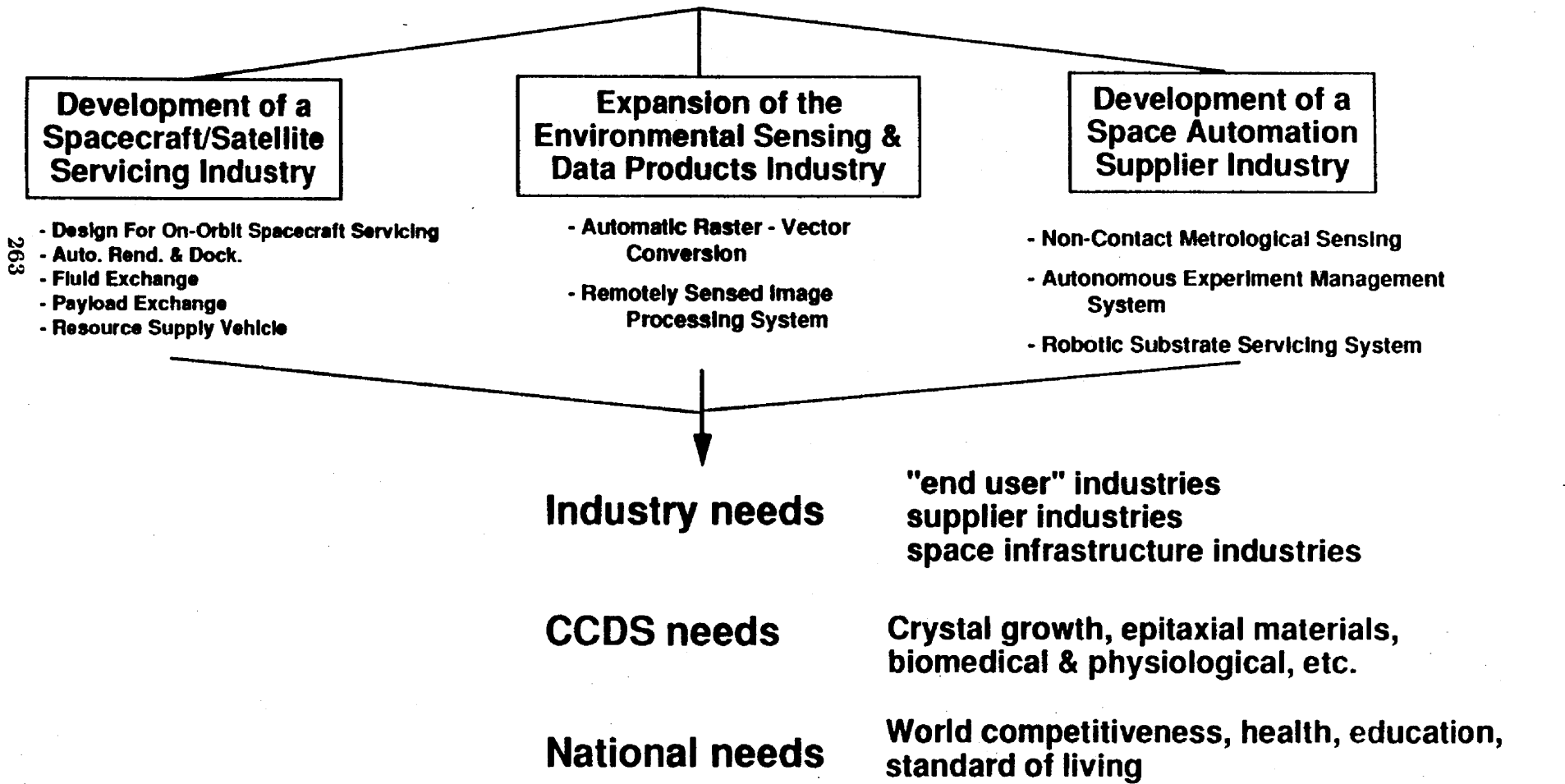
The Space Automation and Robotics Center,  
a NASA Center for the Commercial Development of Space,  
is involved in the following:

"better, faster, cheaper" programs  
under the guidance of NASA  
Office of Commercial Programs

Autonomous Rendezvous and Docking  
Robotic Substrate Servicing System  
Robotic Material Processing System  
Automated Space Production Experimenters Network

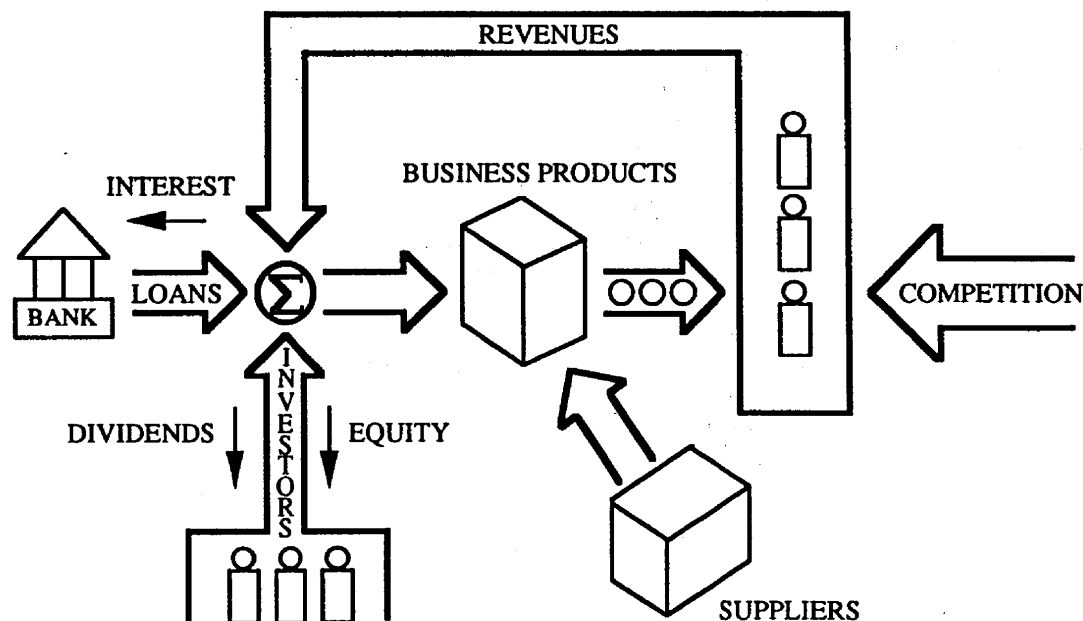
---

**Mission : Facilitate the commercialization of space and space technologies through the application of automation.**



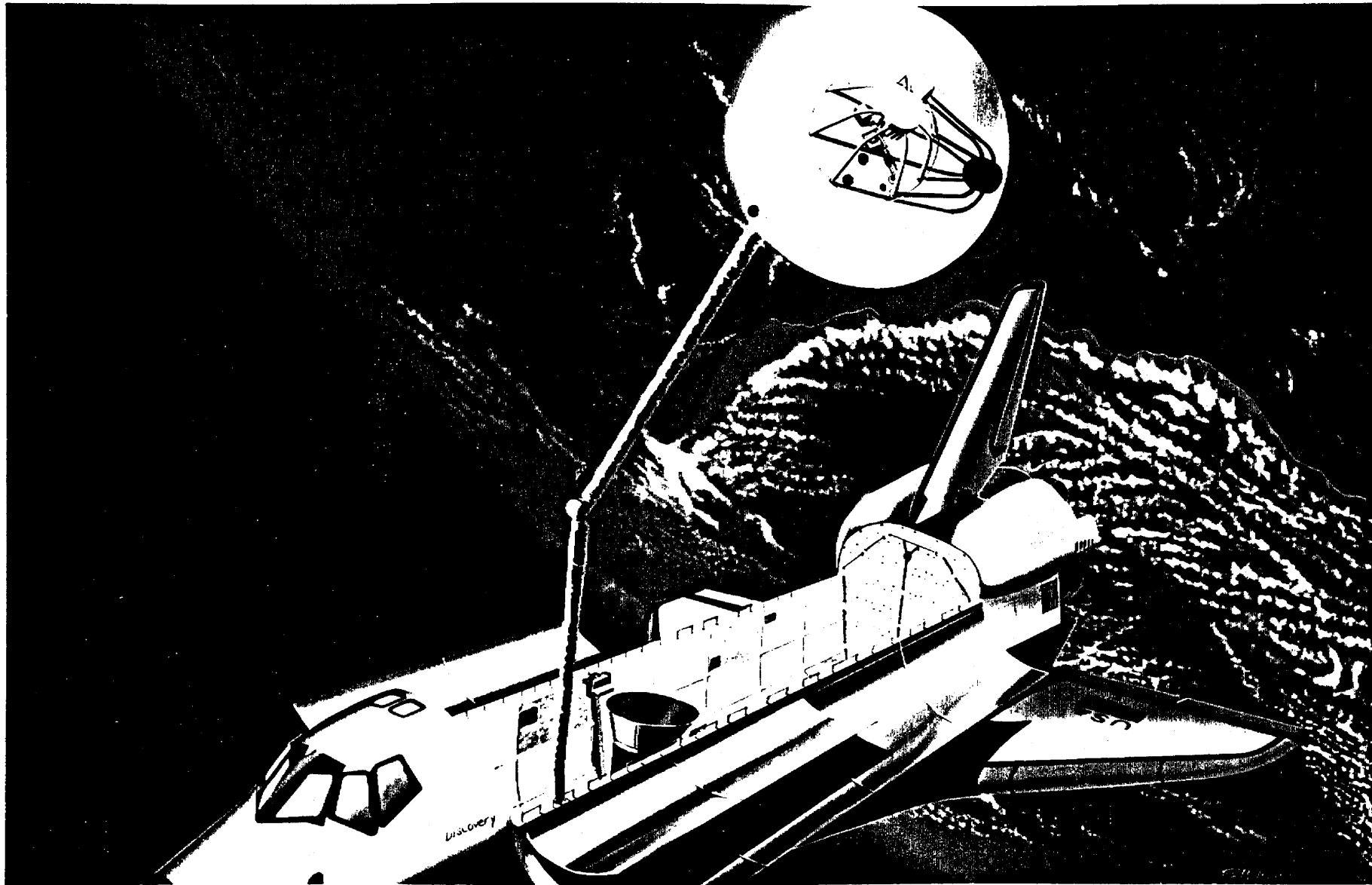
## Why is Autonomous Rendezvous and Docking Important?

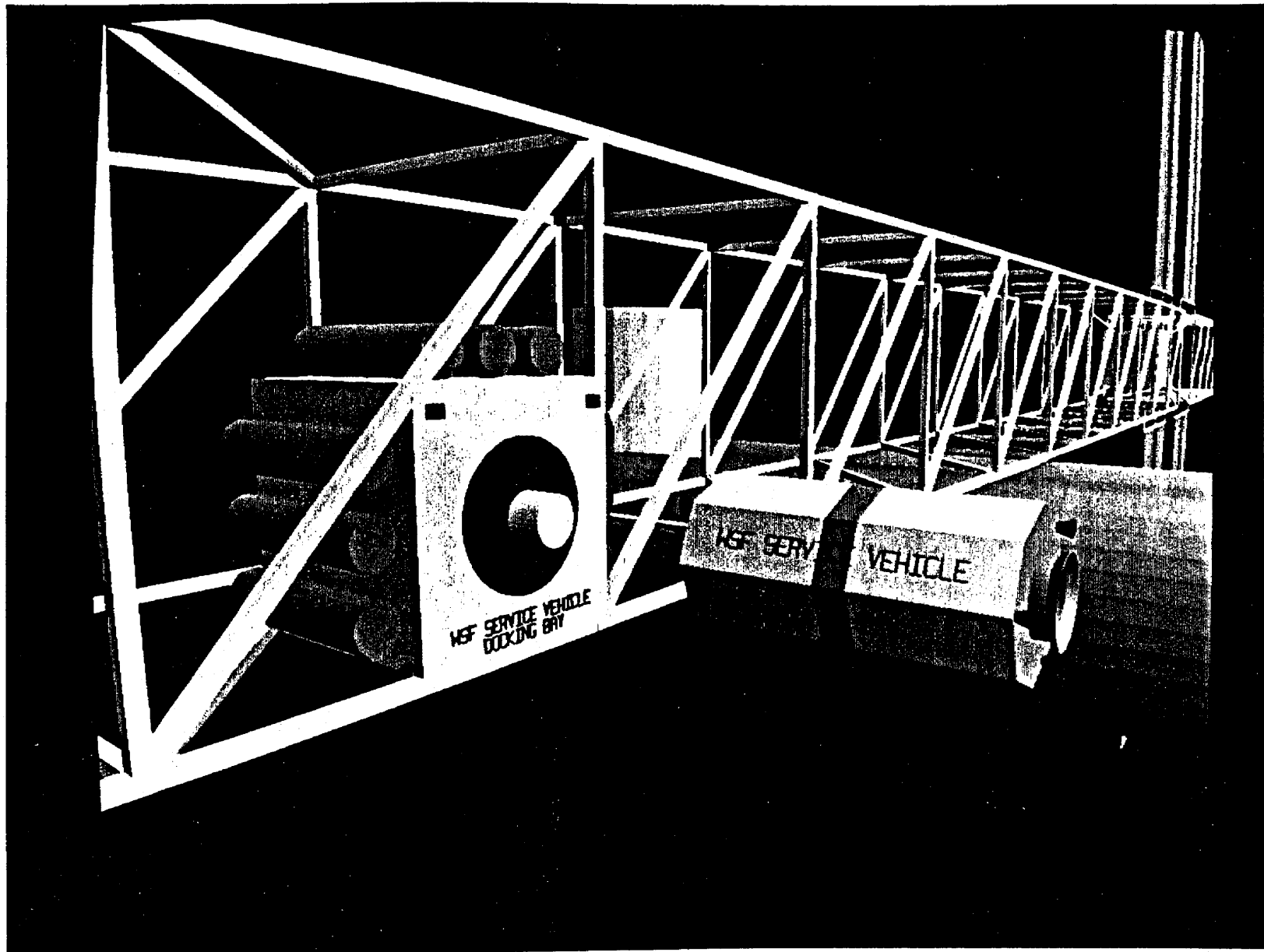
The commercialization of space based manufacturing requires guaranteed product quality, cost and availability.



The Wake Shield Facility is the first such production platform that will be "serviced" by an ELV based system.

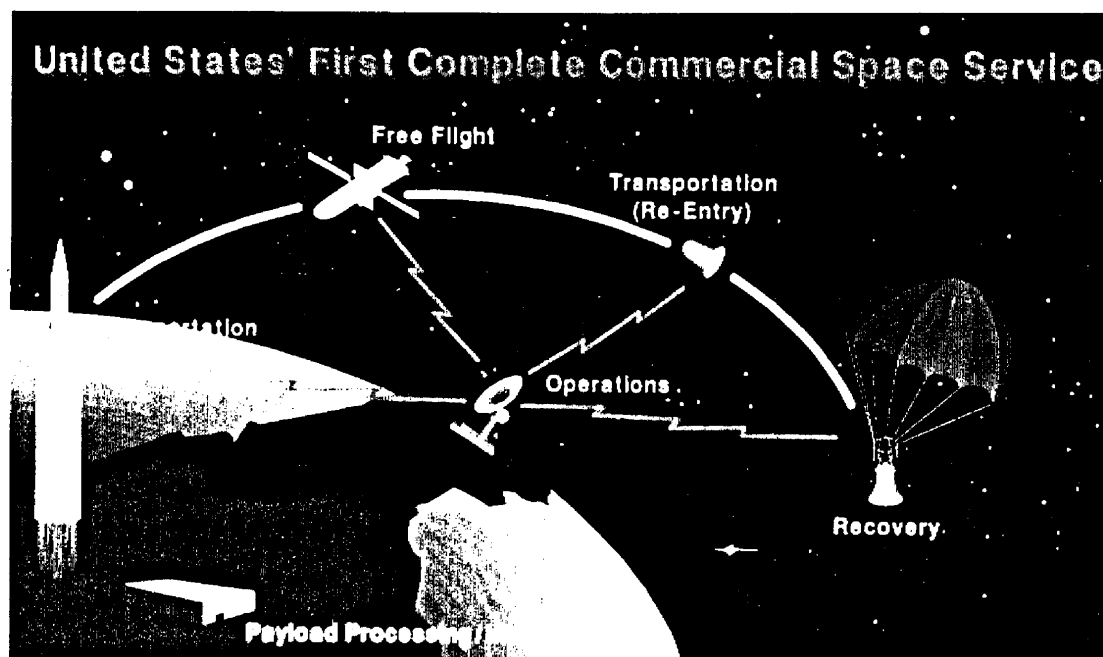






# COMET Overview

91-11917R1

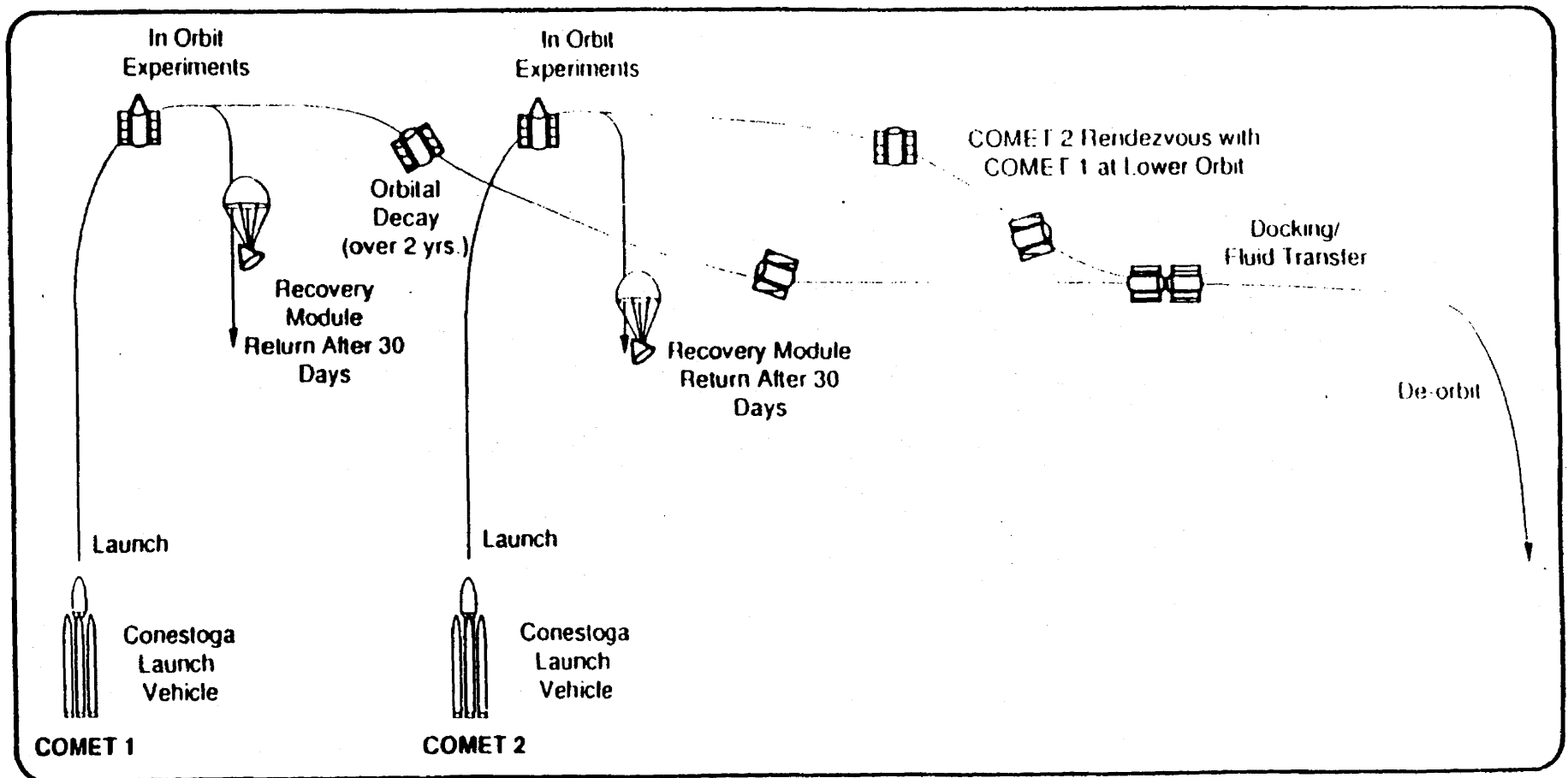


- Principle Spacecraft elements
  - Launch vehicle (Conestoga)
  - Service Module
  - Recovery Capsule

- Launch Date
  - COMET 1 - September 9, 1992
  - COMET 2 - August 1994
  - COMET 3 - August 1995

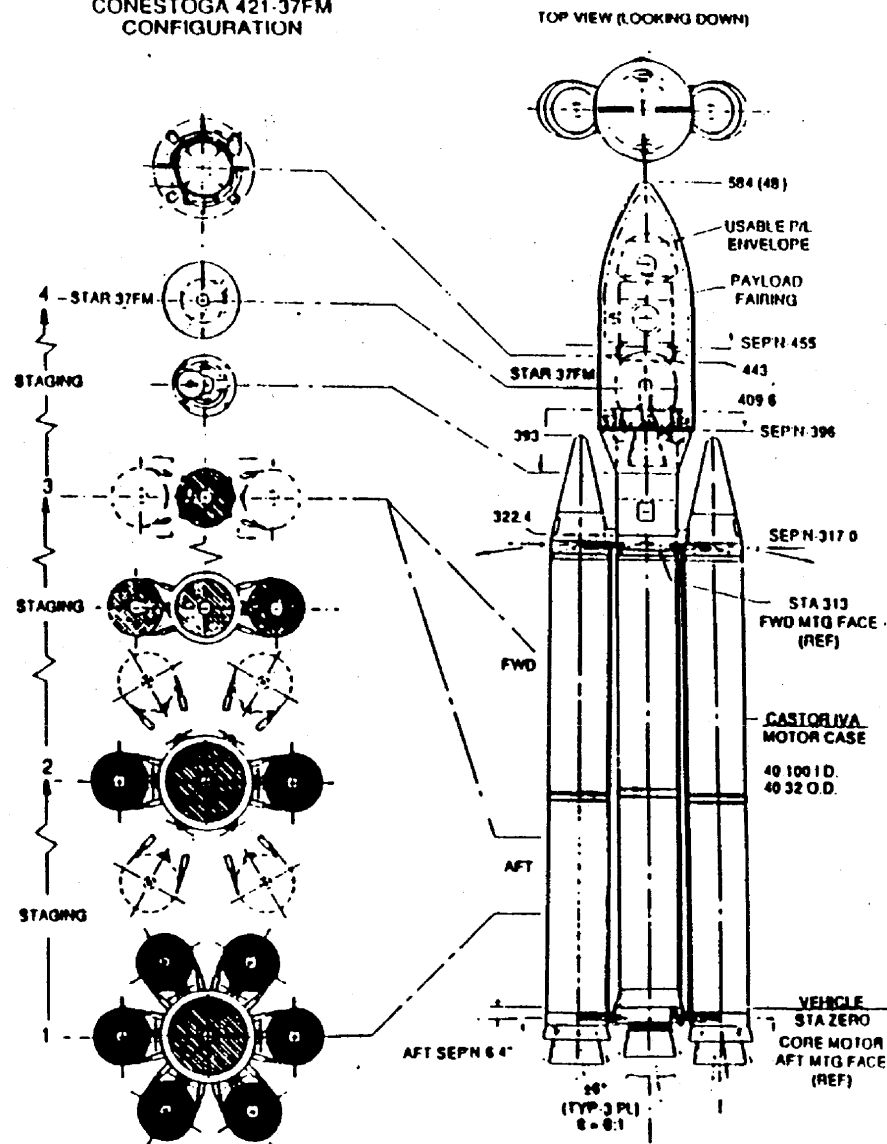
# ARD Mission Profile

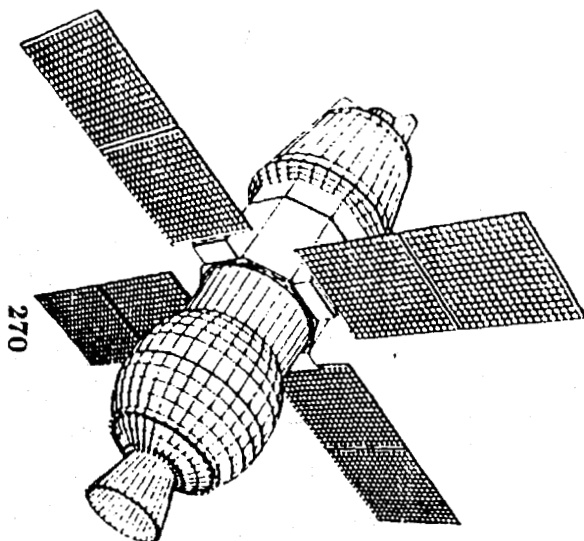
268



# Conestoga Launch Vehicle

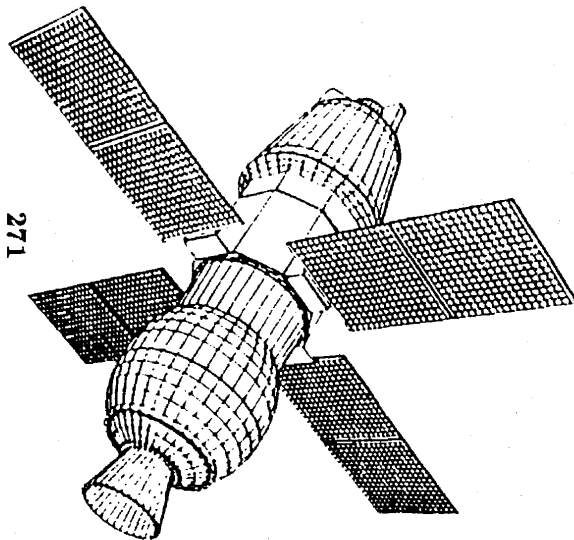
CONESTOGA 421-37FM  
CONFIGURATION



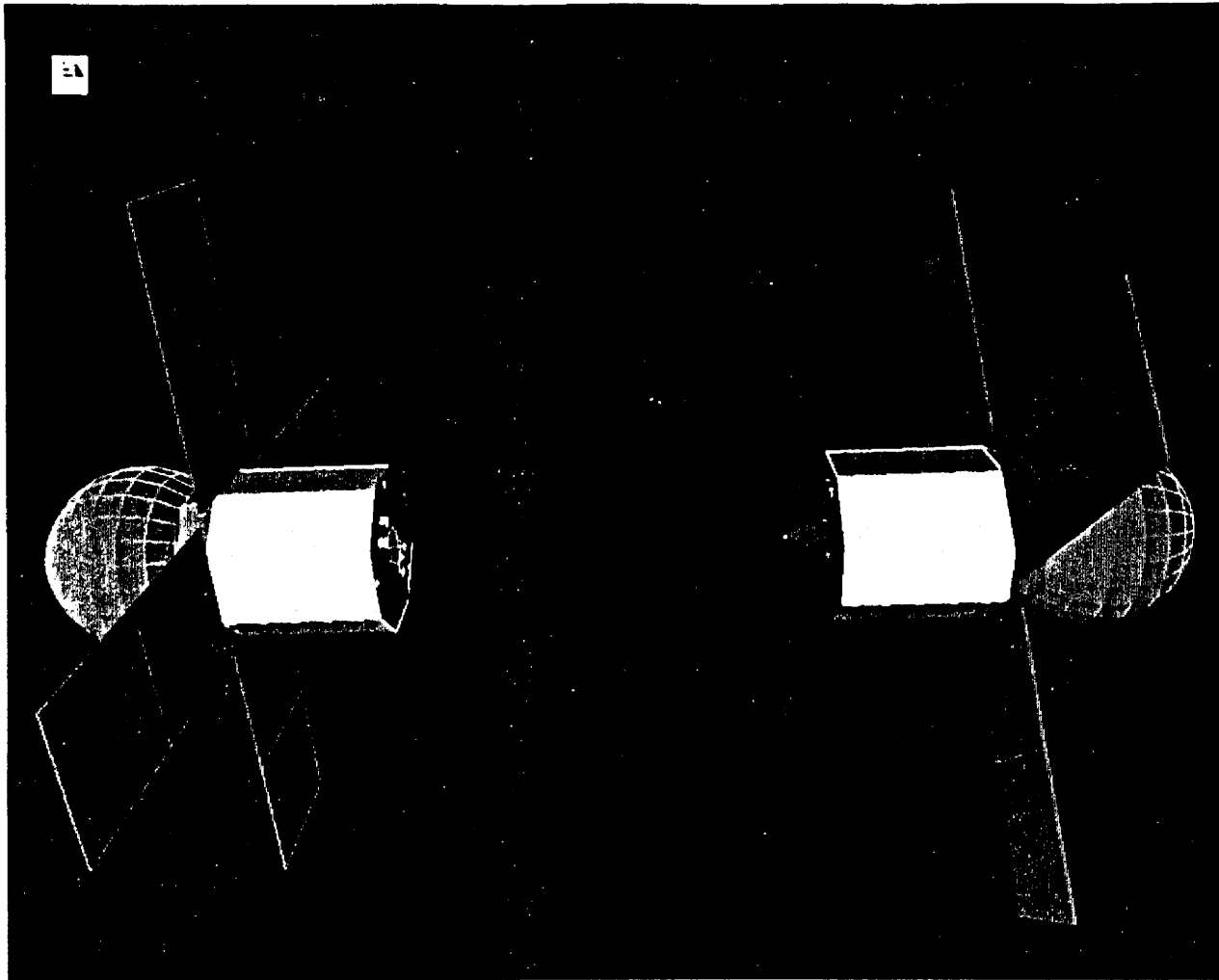


Parameter	Capability
Mission Duration	Recovery Module/Service Module Exp.'s: 30/100 days ARD Experiment (Service Module): 2 yrs + (beyond baselined requirement)
Nominal Orbit	300 nmi $\pm$ 20 nmi, 40.6° $\pm$ 0.2° incl
Microgravity Level	< 10 <sup>-5</sup> G's continuous
Attitude Pointing	Sun Ptg. $\pm$ 0.5° (fine sun sensor) Earth Ptg. $\pm$ 5° (reaction wheel, momentum bias mode) Any Orientation $\pm$ 0.5° (limited periods)
Attitude Control	3 Axis Active Control

## COMET Service Module Payload Accommodation Parameters



Parameter	Capability
Total Payload Weight	150 lbs. minimum
Total Payload Volume	Approx. 15 cubic feet
Power Available <ul style="list-style-type: none"> <li>- continuous</li> <li>- peak</li> <li>- voltage</li> </ul>	350 W 400 W for 200 hrs. $28 \pm 4$ VDC
Heat Rejection	Approx. 570 W
Internal Environment <ul style="list-style-type: none"> <li>- pressure</li> <li>- temperature</li> </ul>	Vacuum $72^{\circ} \pm 5^{\circ}$ F at baseplate
Communications (half duplex) <ul style="list-style-type: none"> <li>- cmd uplink</li> <li>- data downlink</li> <li>- video dwnlnk</li> <li>- frequency of transmissions</li> </ul>	9.6 kb/sec 250 kb/sec Merged with data downlink Average: 5 pass/day, 40 min/day

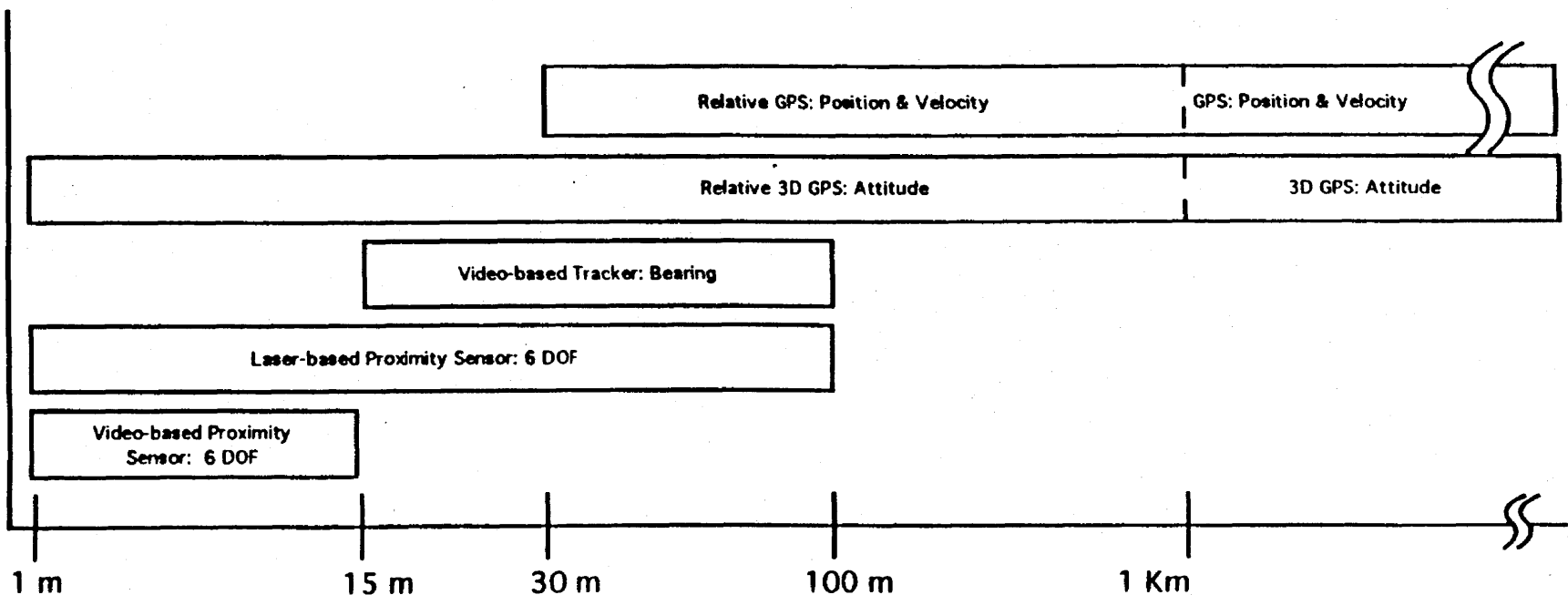


COMET 1 Docking with COMET 2



## Conceptual Design and Hardware Status 12 Months Prior to Launch

# **Future Rendezvous and Proximity Operations: Sensor Data as a Function of Range and Sensor**

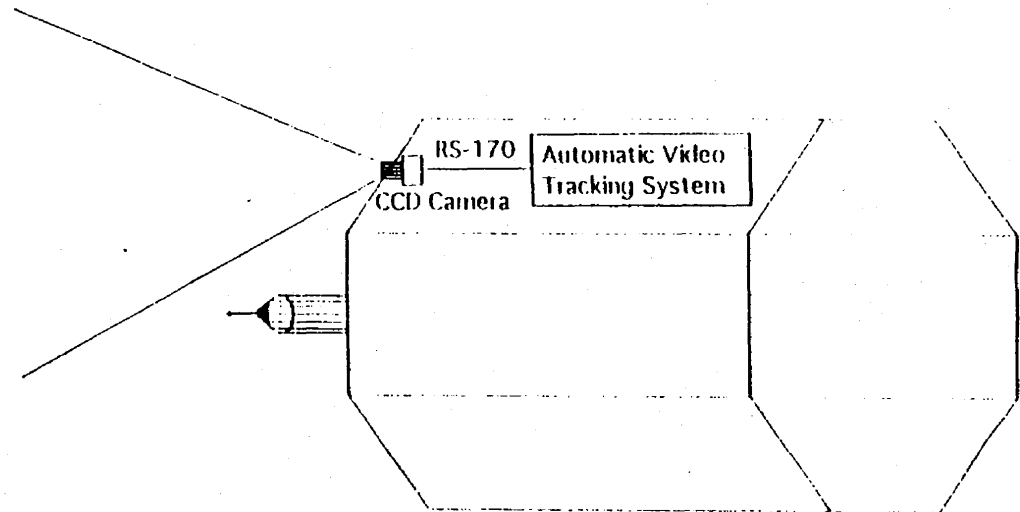
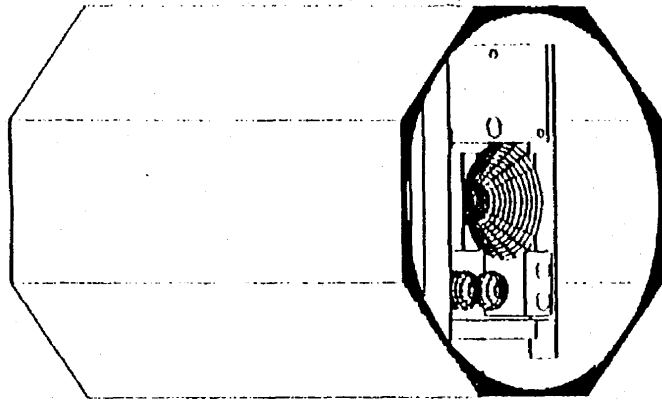


**RANGE**  
**(Relative Position Between Spacecraft)**

ENGINEER P. TCHORYK	DRAFTSMAN S.J. CARR	
SPACE AUTOMATION & ROBOTICS CENTER	Rendezvous & Proximity	11/11/91
ENVIRONMENTAL RESEARCH INSTITUTE of MI	Operations for ARD	10/17/91
ANN ARBOR, MI	Cont'd 011-113	DATE

# Automatic Video Tracking System

275



## COMET 1

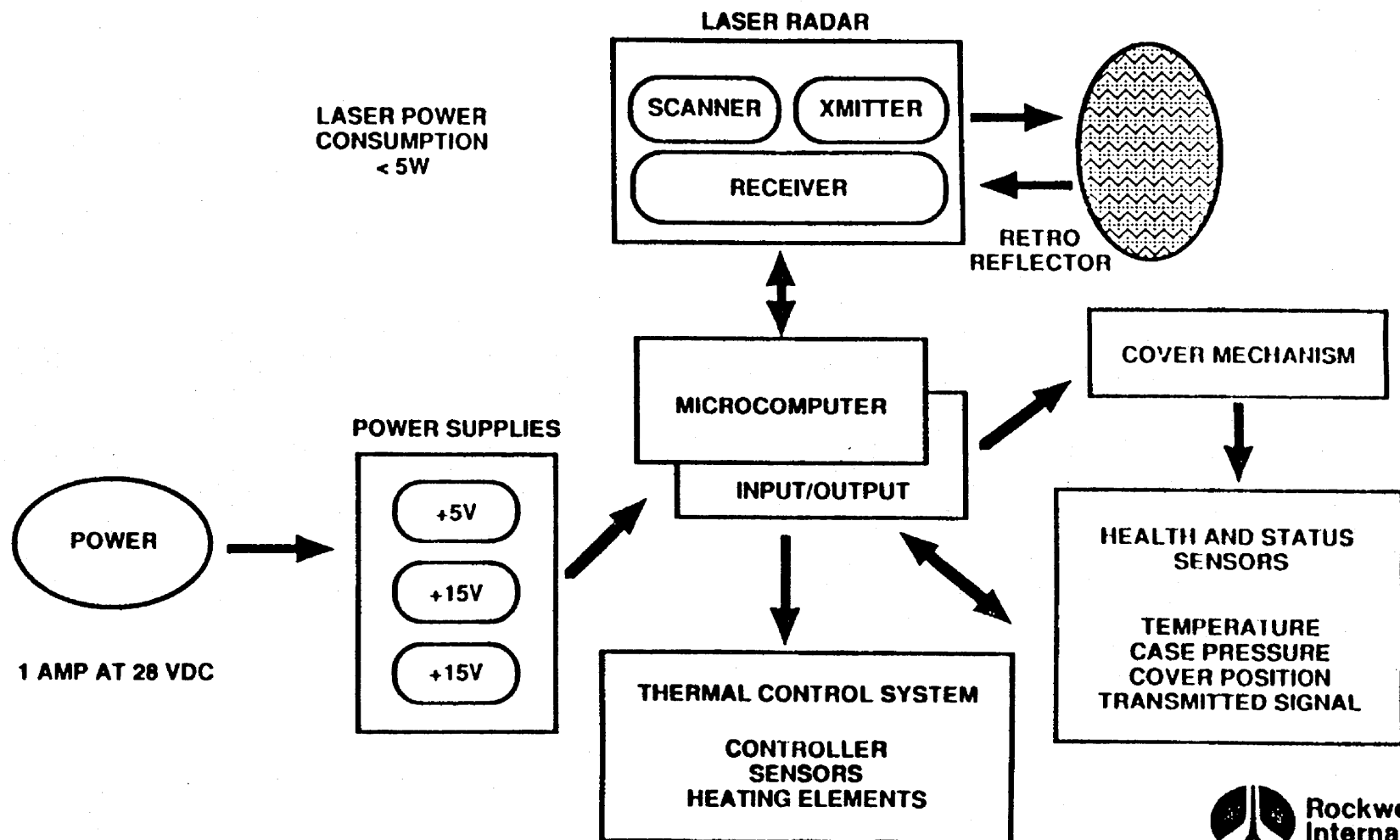
- A quartz halogen lamp allows tracking at distances from at least 100 m down to 15 m

## COMET 2

- An automatic video tracking system will be used to provide bearing to COMET 1
- The video tracking system (a modified commercial unit) will track the lamp on COMET 1 using a standard b/w video camera as the imaging device

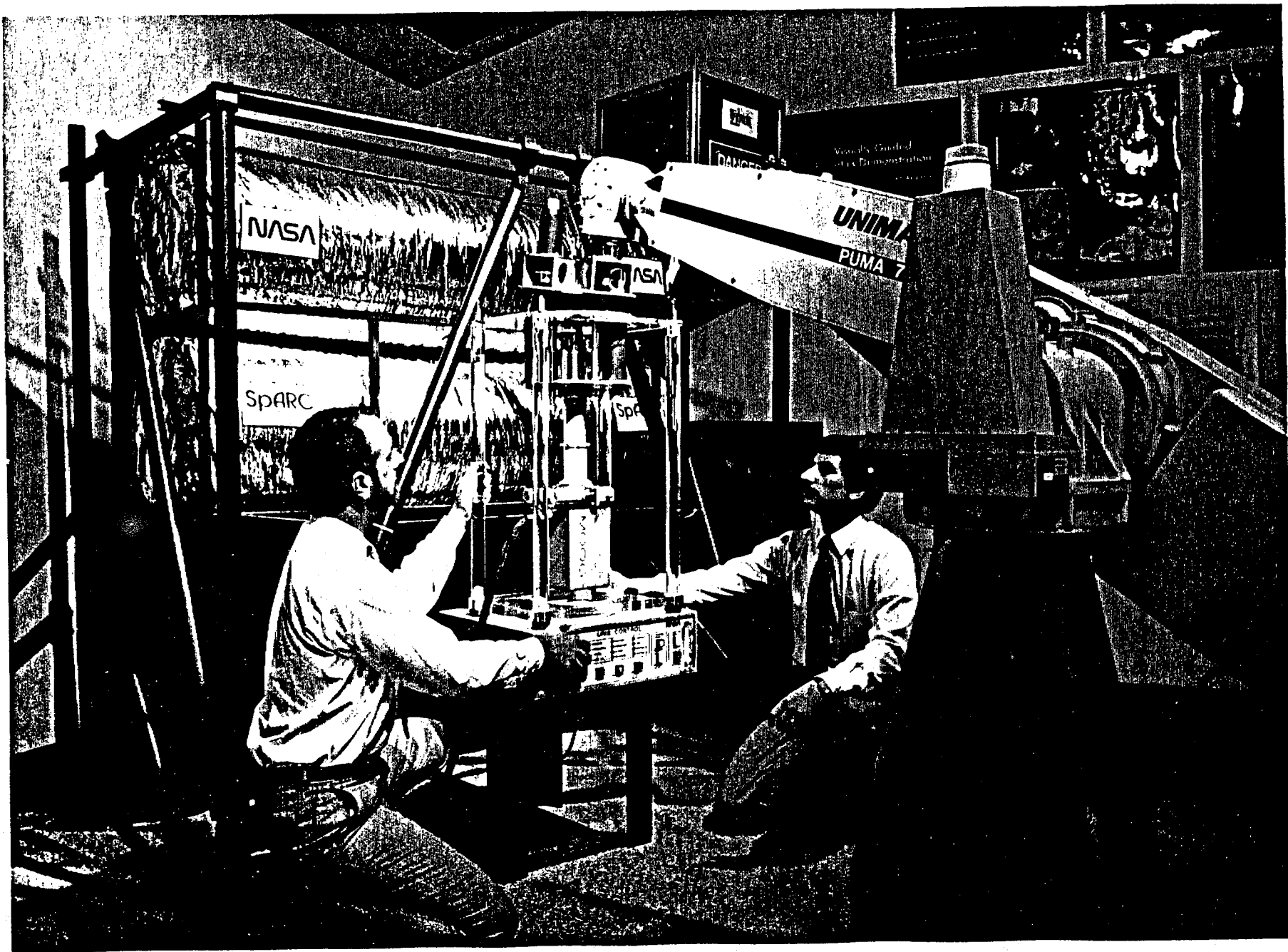
# Rockwell Laser Docking Sensor

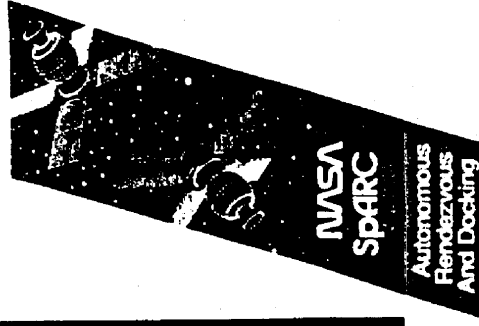
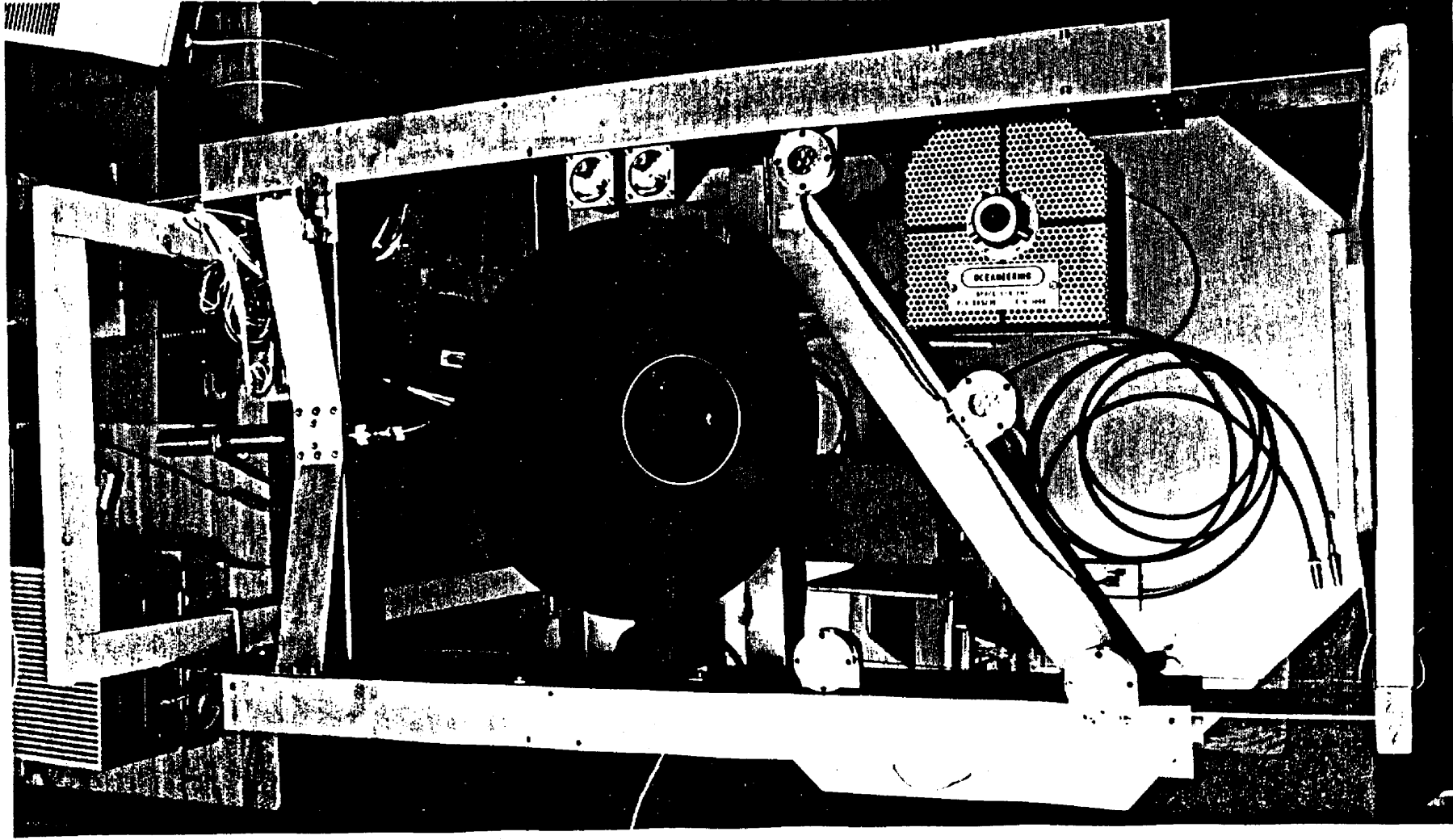
## Block Diagram

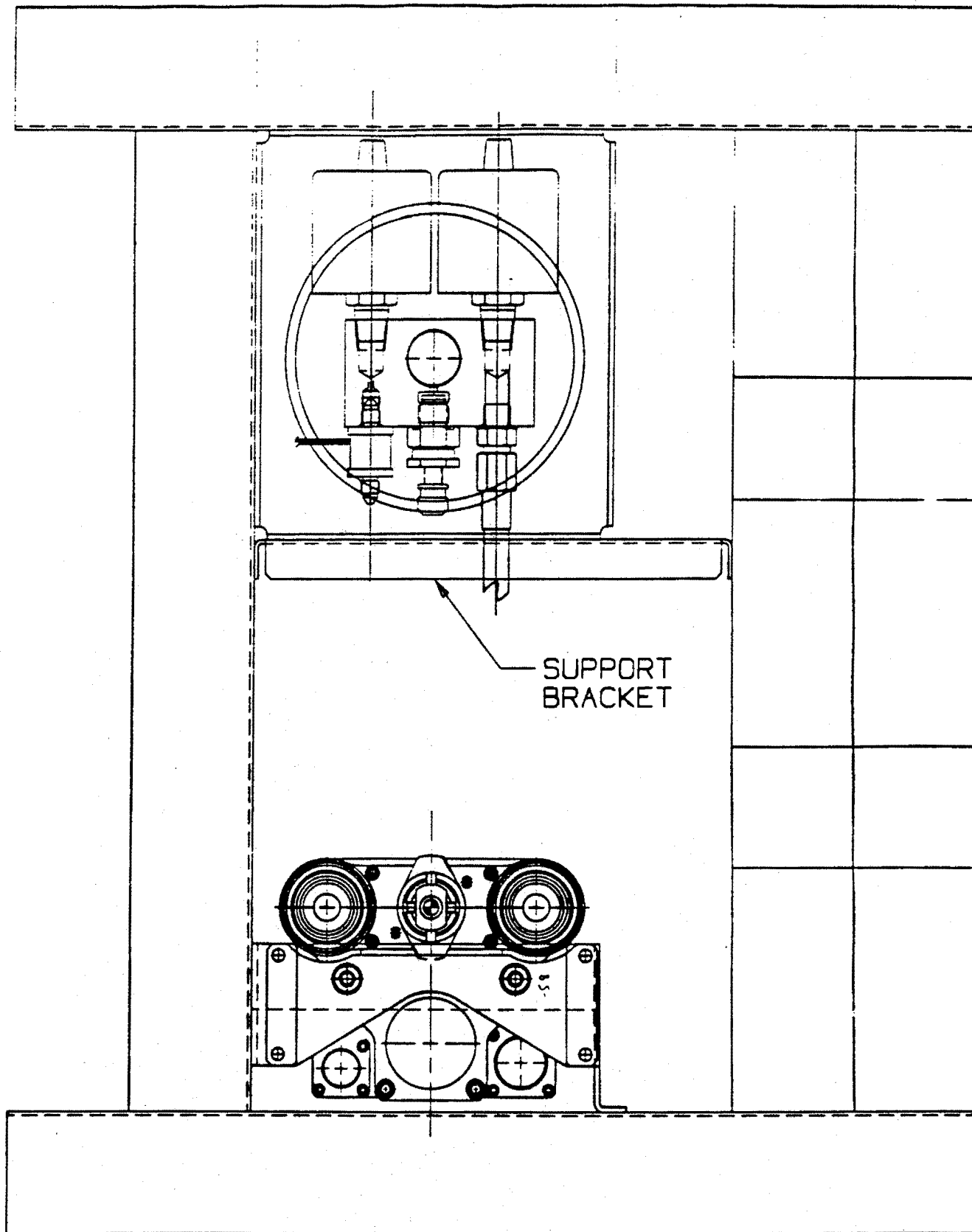


## Design Requirements

- **Operating Range**
  - max > 150 meters (500 ft)
  - min < 0.3 meters (1 ft)
- **Accuracy**
  - range < 3.0 mm (0.01 ft)
  - range rate < 3.0 mm per second
- **Field of Regard  $\pm 20^\circ$**
- **Update Rate > 1 Hz**
- **Eye Safe ( < 0.1 W per sq meter)**
- **Low Total System Power (28 W max, including processing)**
- **Compact Size/Wt (< 0.06 cu meter, < 23 kg)**





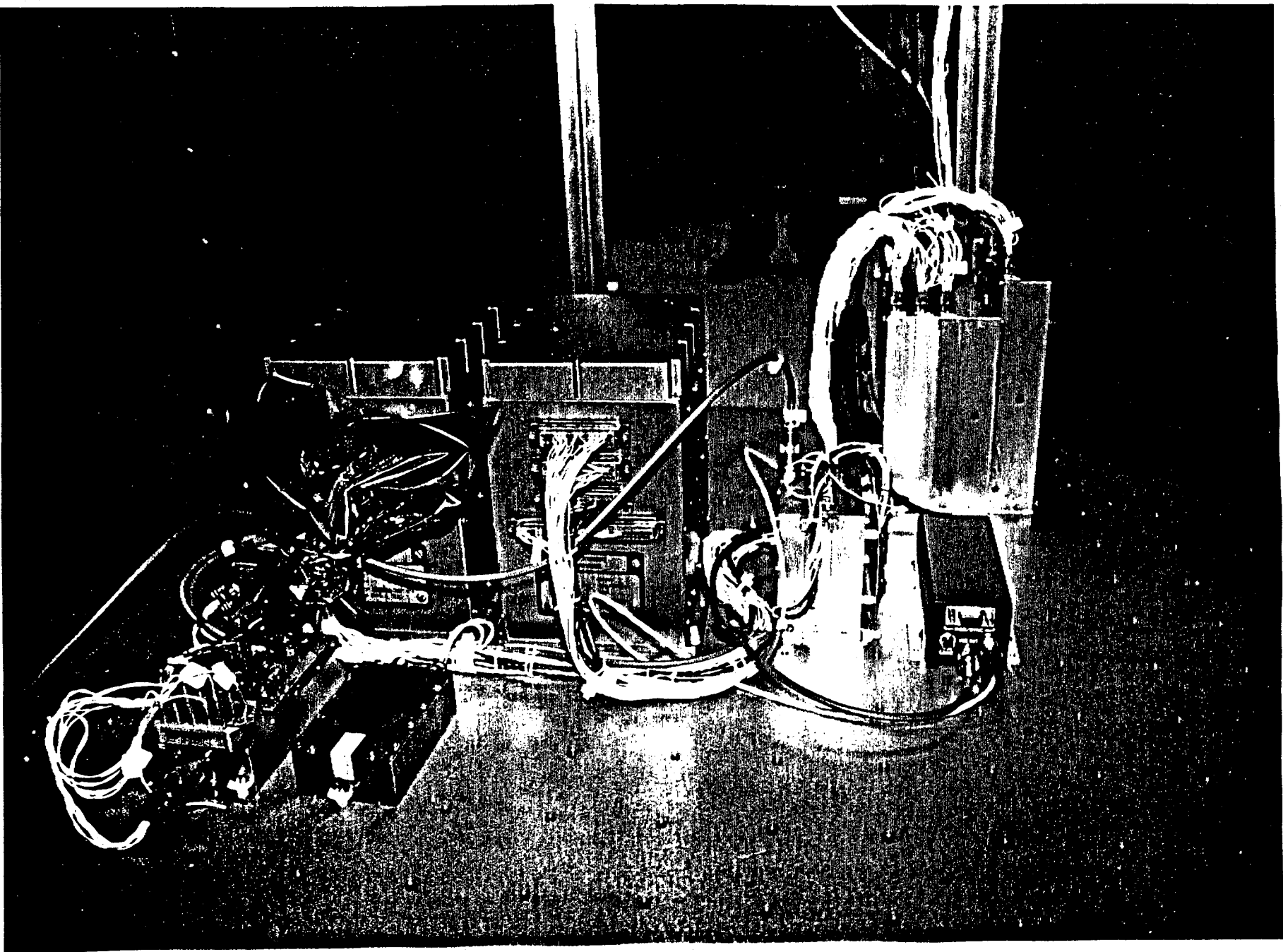


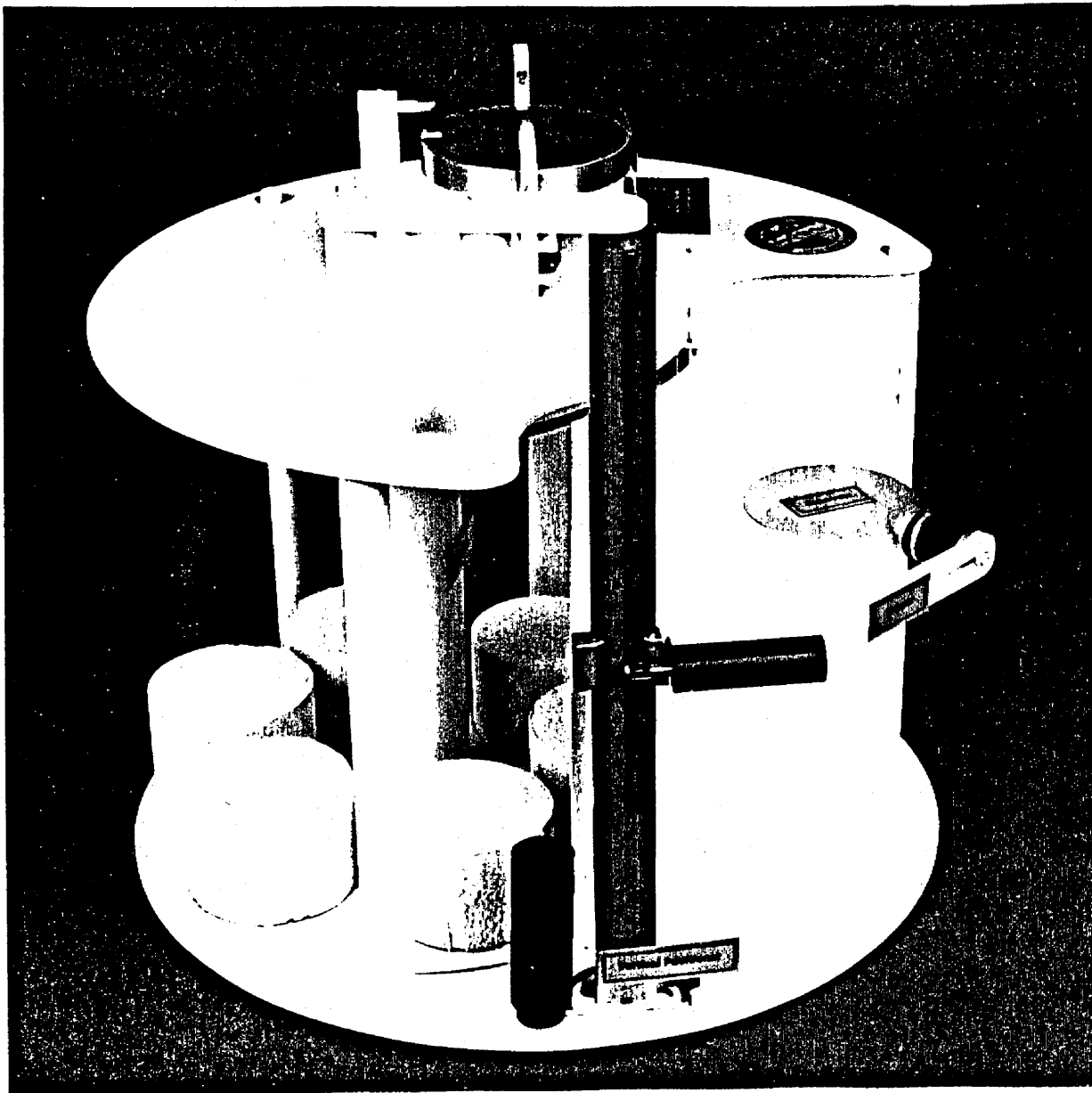


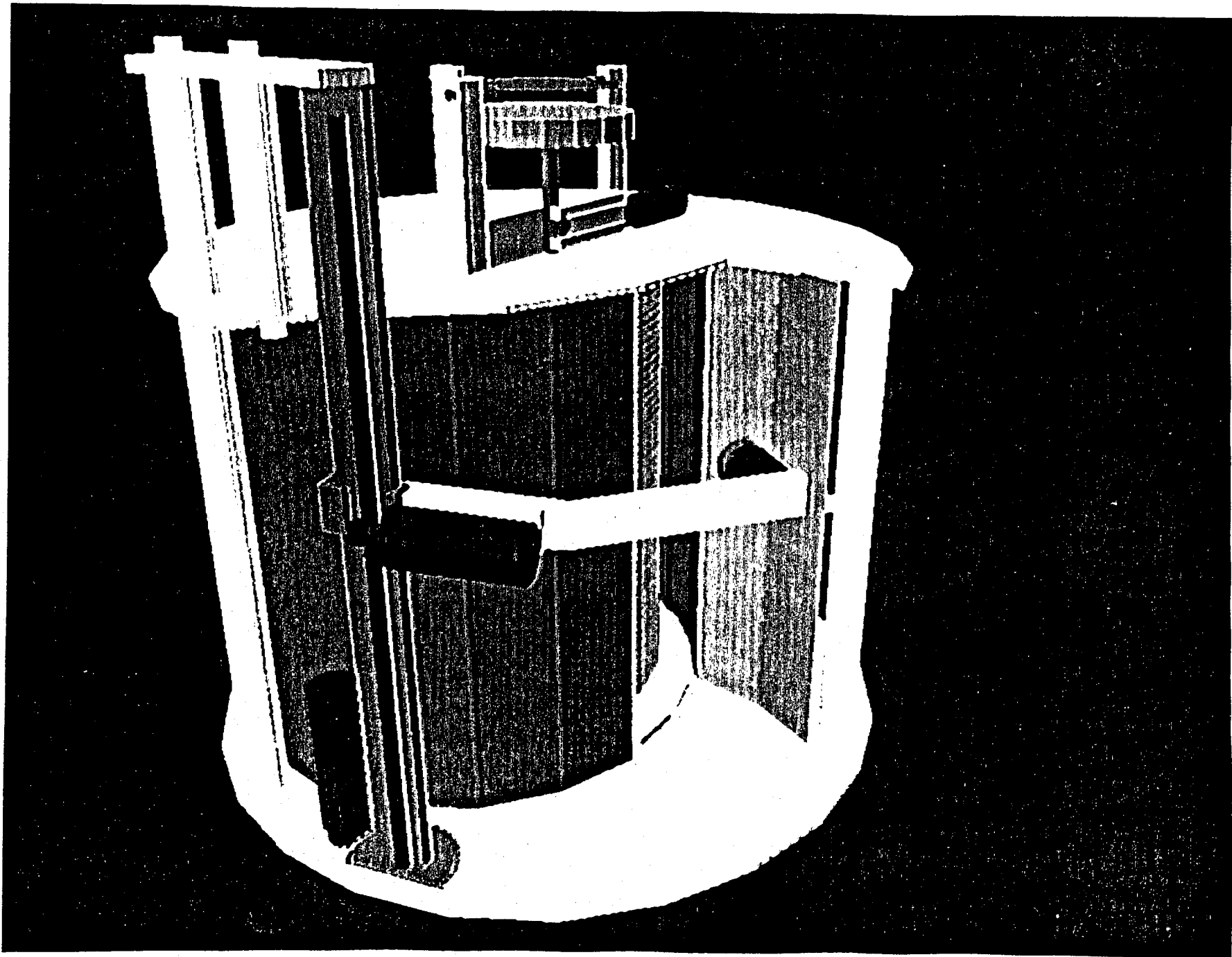
# MOOG FQDC Specifications

---

Parameter	Passive Half	Active Half
Size (LxWxH in)	2.2 x 6 x 6	4.2 x 6.4 x 6.5
Weight (lbs)	1.8	5
Power (pk W)	n/a	10

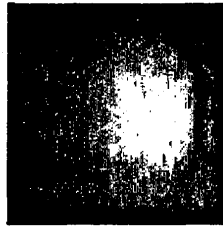




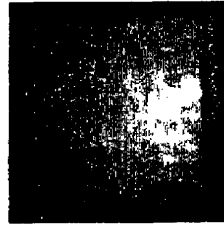


# **CYTO-HSS® IMAGE PROCESSING FOR REFLECTANCE HIGH ENERGY ELECTRON DIFFRACTION (RHEED)**

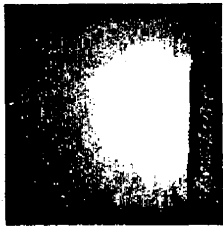
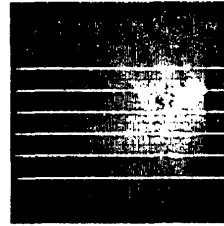
90-11190



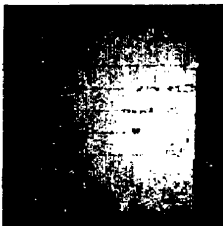
This Algorithm Determines if the Substrate Has Been Heated Sufficiently for Epitaxy to Occur. The Lack of Intensity Streaks Indicates That Further Outgassing Is Required.



This Algorithm Is Used to Identify the 2F Reconstruction Pattern, From Which a Subset of the Lattice Constants Are Determined



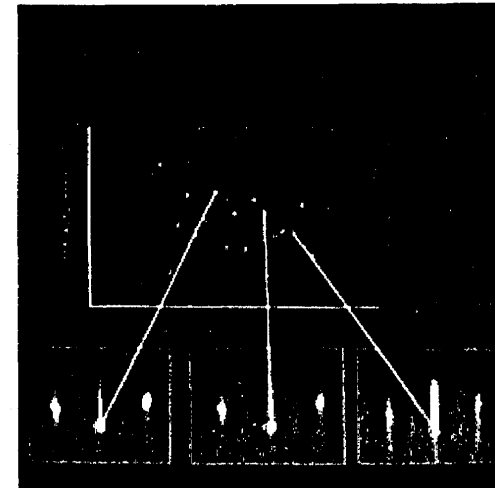
This Algorithm Is Used to Determine When Outgassing Is Complete



This Algorithm Is Used to Identify the 4F Reconstruction Pattern, Which Is Used to Obtain the Remaining Lattice Constants



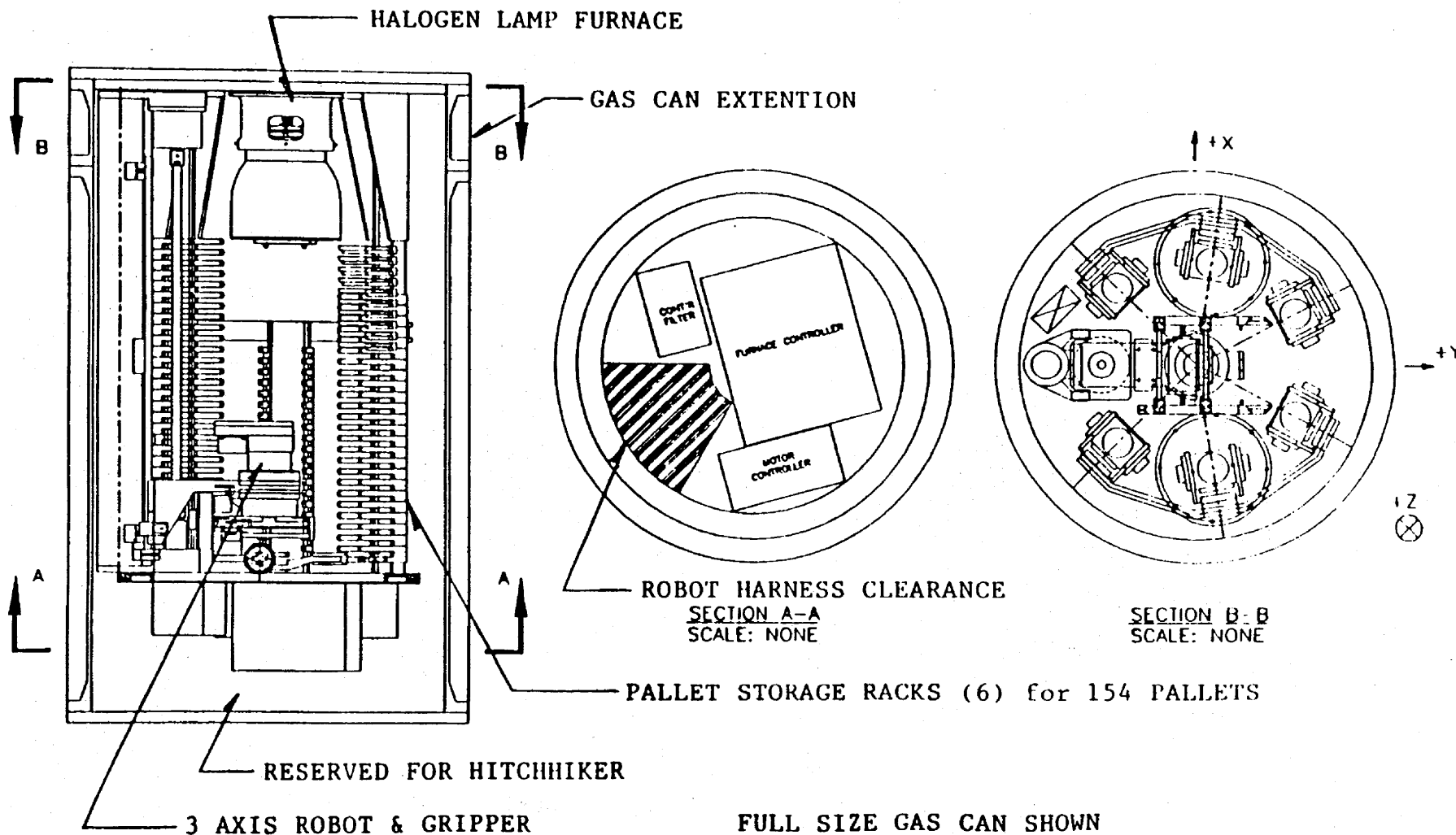
Streak Intensity Oscillation Detection Is Used to Monitor and Count the Layers Deposited by MBE



ERIM's Cyto-HSS Image Processing System Is Capable of Providing Real-Time (10 Frames/sec) Image Processing for the Monitoring of the MBE (Molecular Beam Epitaxy) Deposition Process. The Information Obtained by These Image Processing Algorithms Can Then Be Applied to Process Control of the MBE System.

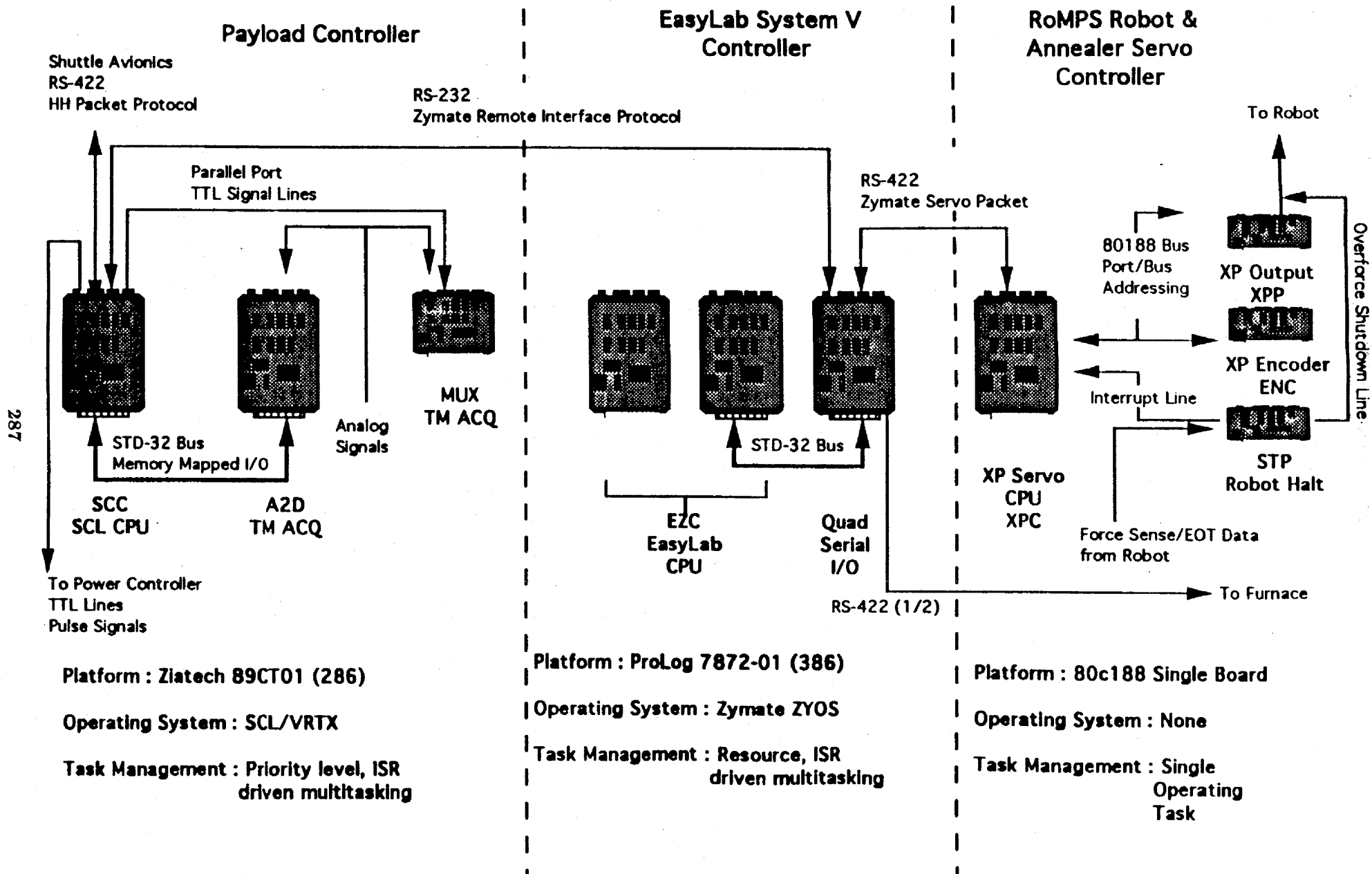
# ROMPS PROCESSING CAN ASSEMBLY

286



**ROMPS**

# RoMPS Payload Software Interfaces/Platforms







# **Spacecraft Guidance, Controls, & Navigation Technology for Small Expendable Technology — Controls**

**Raymond C. Montgomery  
Spacecraft Controls Branch  
NASA Langley Research Center  
Hampton, VA 23665**

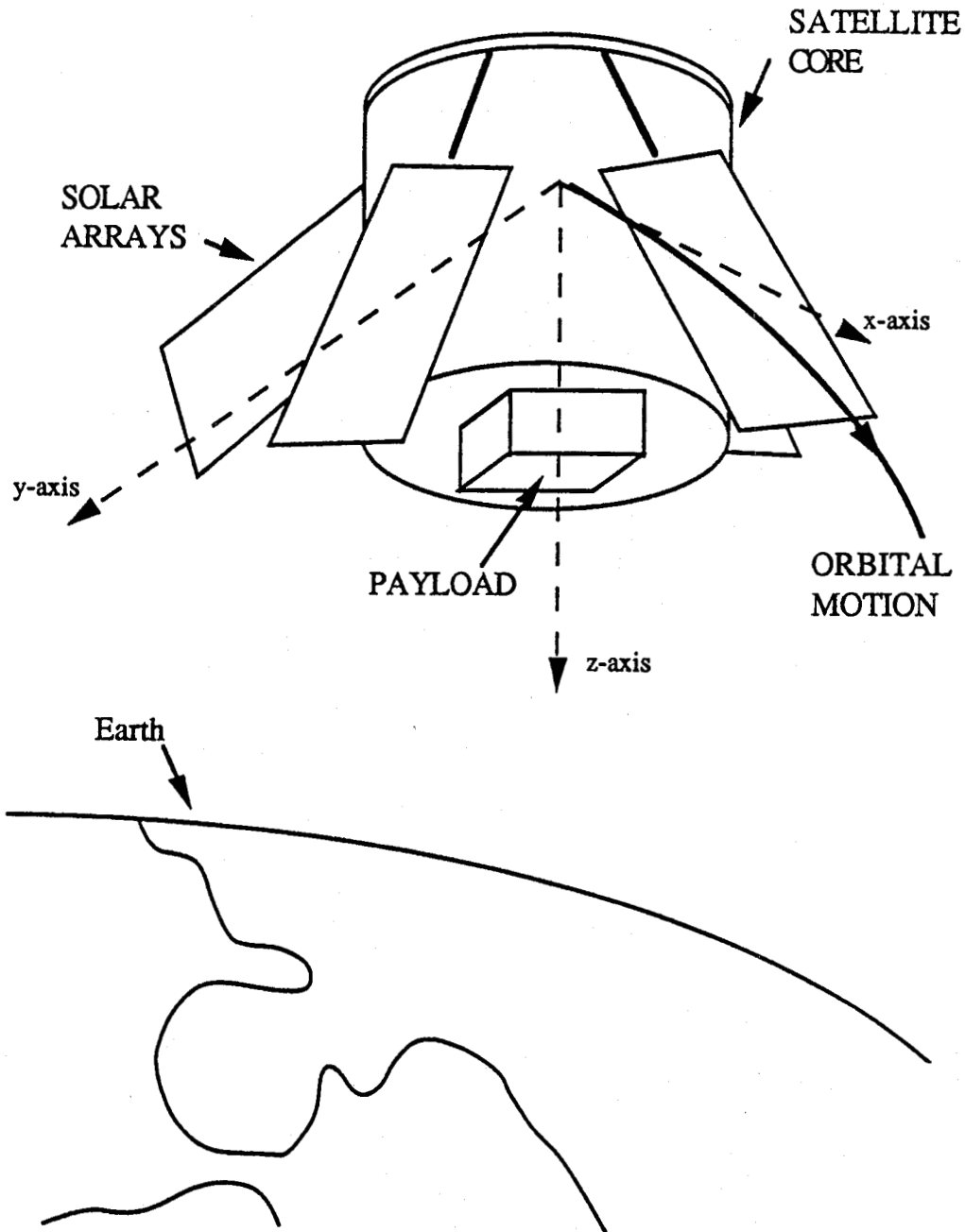
**Presentation at the  
SELV Based In-Space Operation Workshop  
October 18, 1993**

# Background

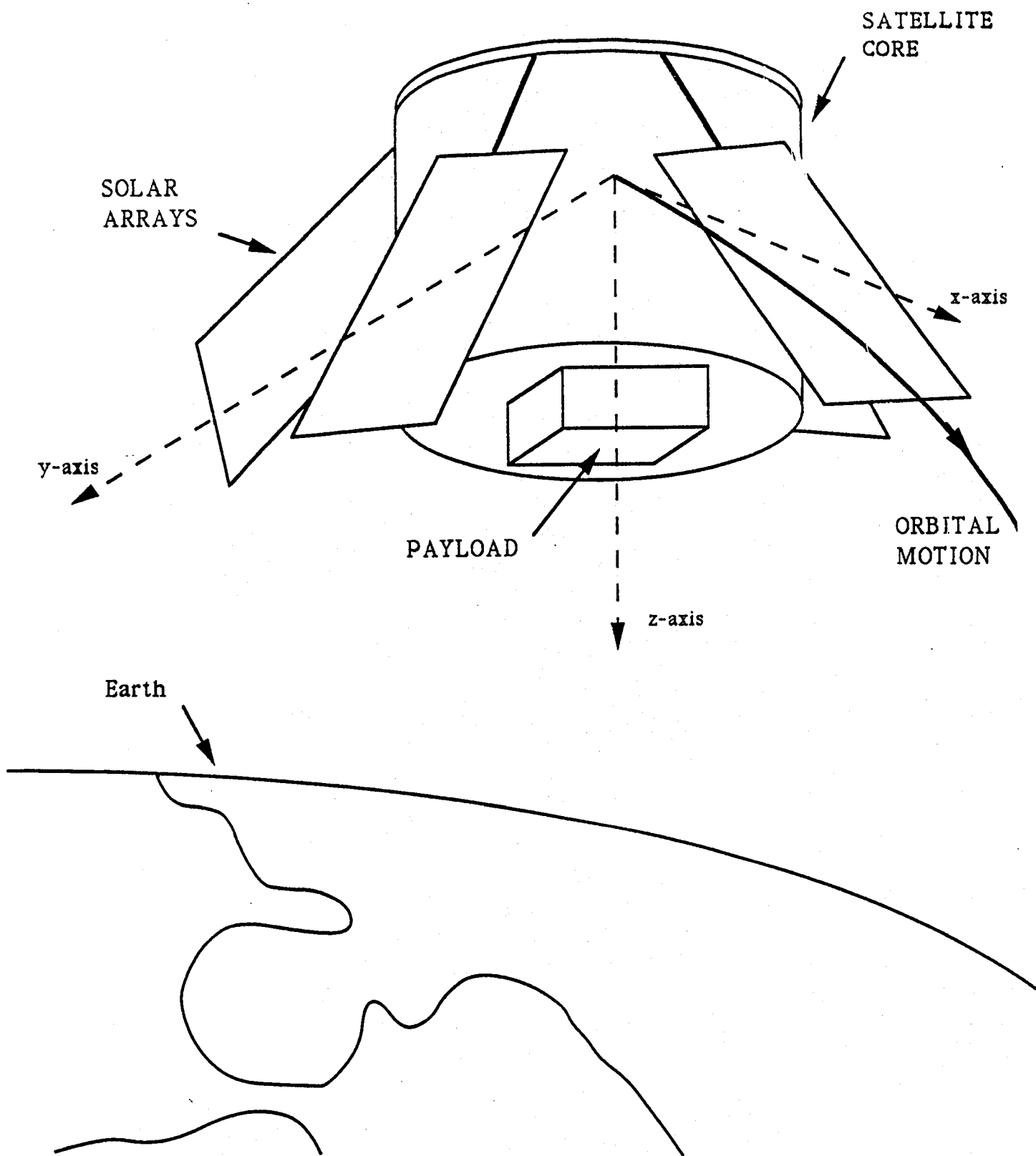
- LaRC GNCTC recommendation, 91-92 term, operated a space platform to allow research an opportunity for space experience in automation and robotics
- Task undertaken to further define in 92-93 term
- result was a facility, operated by NASA LaRC, that gives space research a low-cost access to space
- Models used were the LaRC Scout sounding rocket office at LaRC, the Eagle class spacecraft, and the COMET program

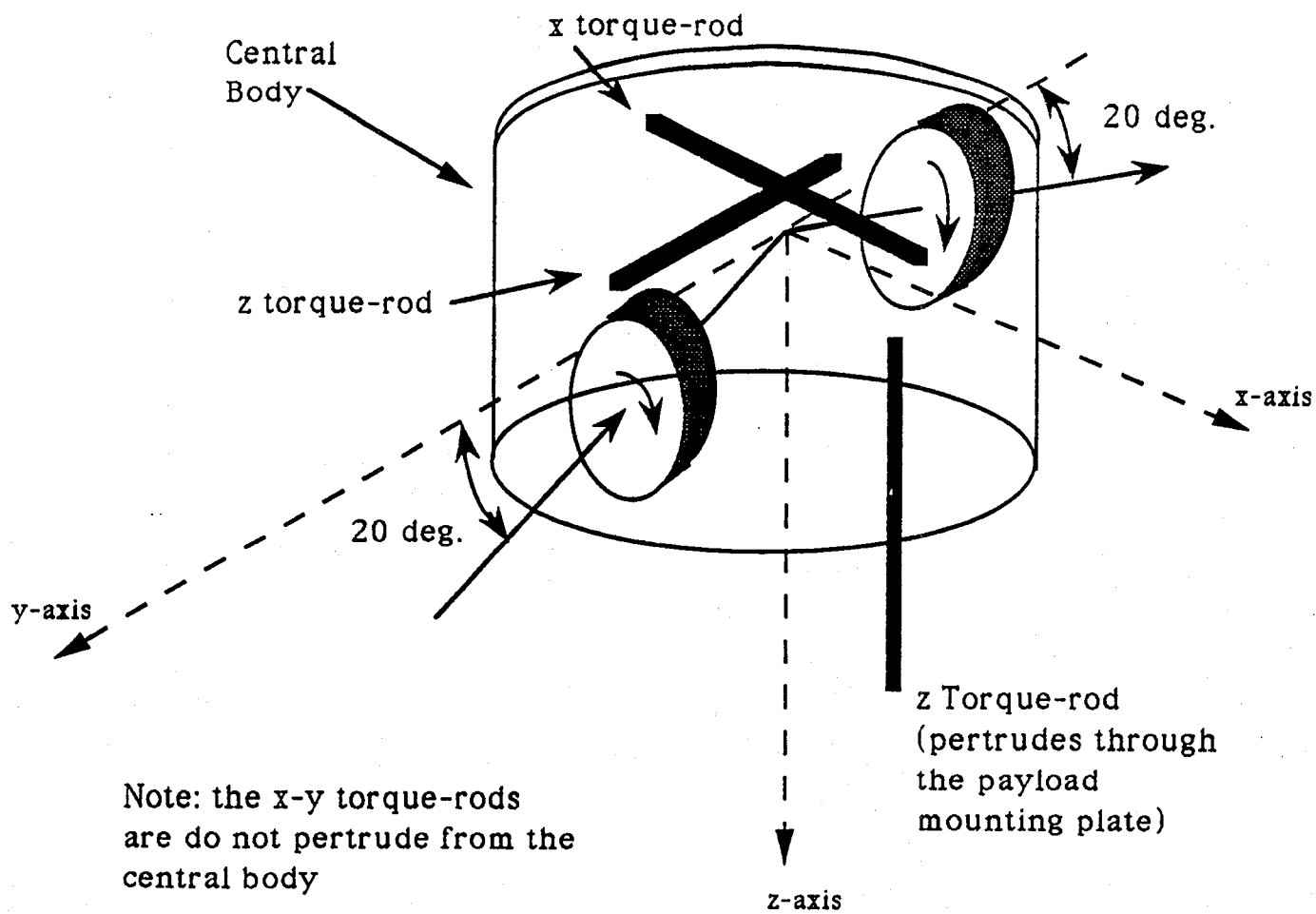
## Equations of Motion for the Eagle Spacecraft Study

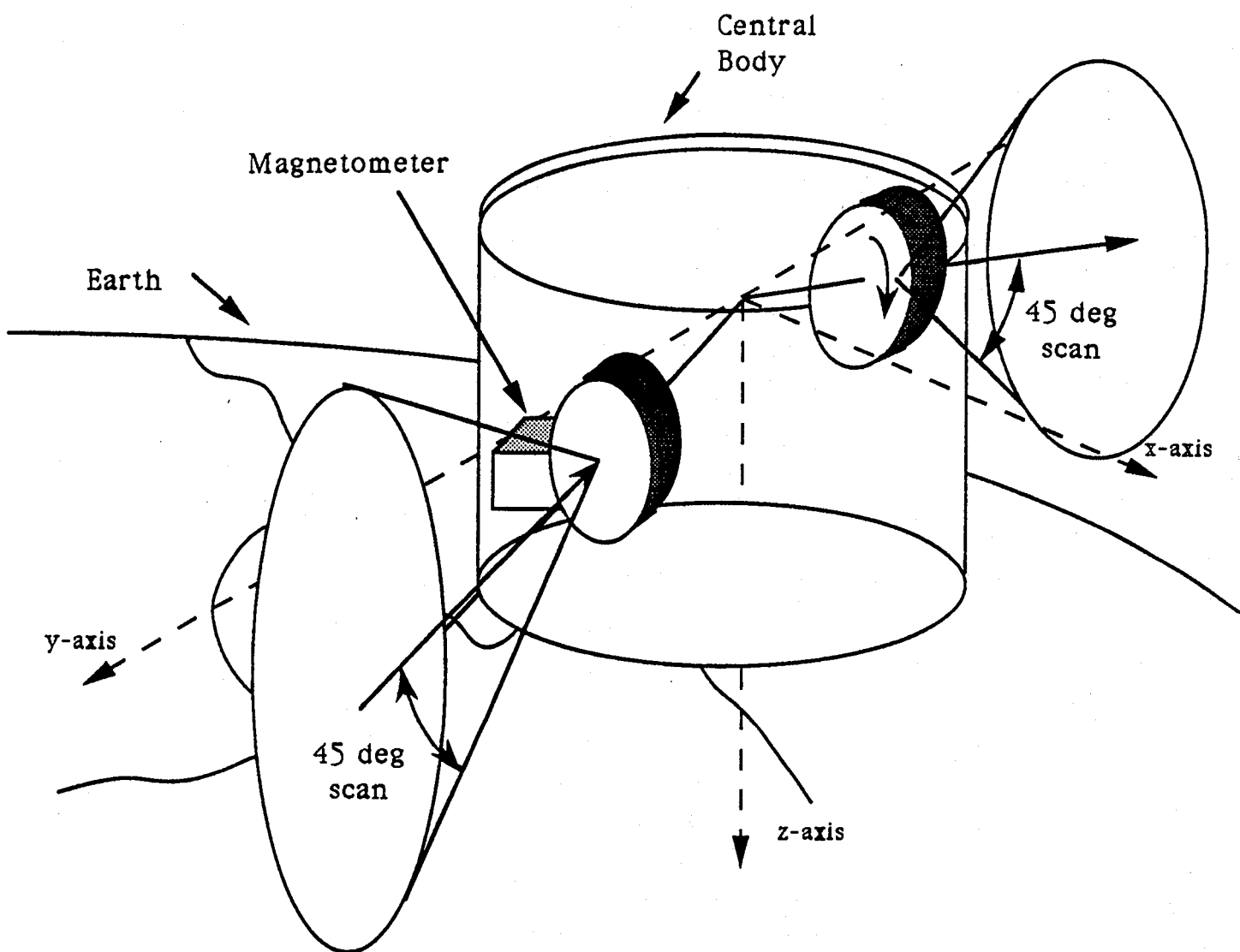
The equations of motion were developed using the axis system shown in the sketch below:



Sketch of the spacecraft showing axis system used.







# Eagle Class Spacecraft — Attitude Control

- 2 Ithaco T-scanwheels ( $1.3 \text{ N-m-s}^2$ )
- Available reaction torque — 20 mN-m
- 3 Ithaco Torqrod electromagnets ( $20 \text{ amp-turn-m}^2$  each)
- 1 Nanotesia NT-600-S three-axis magnetometer
- Electronics assembly

# Requirements for Orbiters

- Full automation with some teleoperation and monitoring
- New experiment packages may contain control system components as well as research in robotics (ORU changeout, fluid transfer, etc.)
  - ☐ momentum, jet, etc., devices
  - ☐ sensor sets
  - ☐ control computer upgrades
- Load Transmission from Payload Module to Core and Main Propulsion Modules
- Sensor view — Earth Nadir, Horizon pointing , and Outer Space
- Changeout of Payload Module
- Resupply of propulsion module, NiCad batteries



# Requirements for Servicers

- Full automation with some teleoperation and monitoring
- Deliver and install a new payload package
  - ☐ momentum, jet, etc., devices
  - ☐ sensor sets
  - ☐ control computer upgrades
- Deliver and supply propellant, batteries, etc.
- Sensor view — Earth Nadir, Horizon pointing , and Outer Space
- Changeout of Payload Module
- Resupply of propulsion module, NiCad batteries
- Docking hardware

# Concluding Comments

- Start by Eagle or COMET type activity
- Develop full automation with some teleoperation and monitoring capability
- Plan for frequent turnaround — 2/year say
- Integrate experiments from industry, academia, and govt. labs into experiment payloads.

# **Global Positioning System (GPS):**

## **Spacecraft Capabilities and Applications**

**Kevin Dutton**  
**NASA Langley Research Center**  
**Spacecraft Controls Branch**

**SELV-Based In-Space Operations Workshop**  
**October 18, 1993**

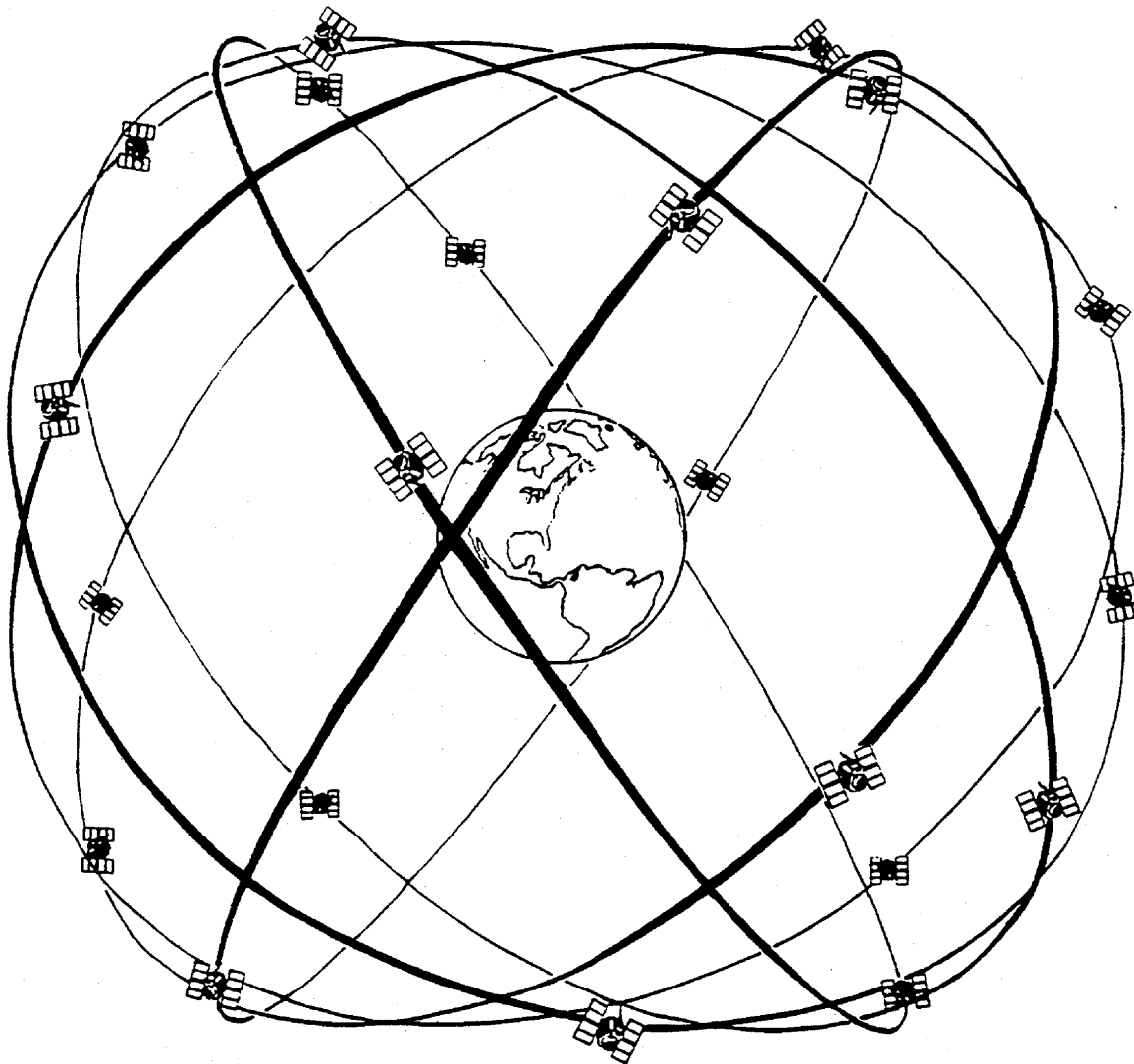
# Outline

- **GPS Overview**
  - **What is GPS?**
  - **Performance specifications**
  - **Error budget**
  - **Operation**
- **Spacecraft applications**
- **Langley GPS activities**
- **Concluding remarks**

# **Global Positioning System**

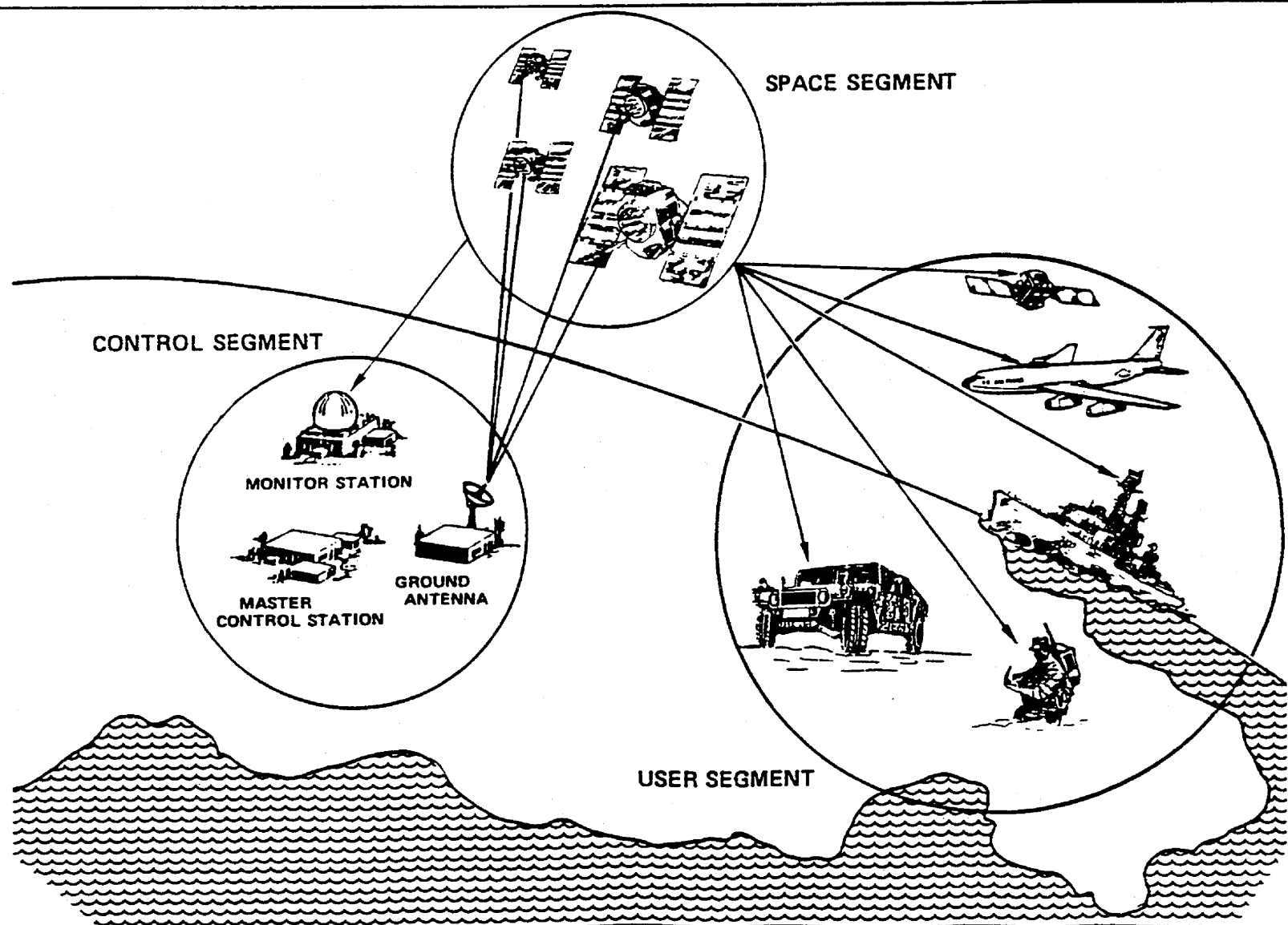
- **SPACE SEGMENT**
  - 24 satellites in 6 orbital planes at 10900 nm circular orbital altitude broadcasting RF signals
- **CONTROL SEGMENT**
  - Master Control Station
  - Monitor Stations
- **USER SEGMENT**
  - anyone with a receiver

## THE DEPLOYED CONSTELLATION



- 21 SATELLITES (PLUS 3 OPERATIONAL SPARES)
- 55° INCLINATION
- REPEATING GROUND TRACKS (23<sup>h</sup>56<sup>m</sup>)
- 4 SATELLITES ALWAYS IN VIEW

# GPS SYSTEM



# System Characteristics

- High accuracy
- Global, continuous access
- All-weather
- Passive operation



# **System Accuracy Specifications**

**PPS Position: 16 m Spherical Error Probable**

**PPS Velocity: 0.07 m/sec**

**PPS Time: 68 nsec**

**SPS Position: 40 m Circular Error Probable**

**SPS - Standard Positioning Service**

**PPS - Precise Positioning Service**

**All quantities are 50th percentile**

# Range Error Budget

	<u>C/A Code</u>	<u>P Code</u>
Satellite Clock and Ephemeris	3.9	3.9
Ionospheric Delay	9.0	0.1
Tropospheric Delay	2.0	2.0
Receiver Noise	4.0	1.1
Multipath	5.0	1.2
Selective Availability	30.0	

Values are one sigma in meters

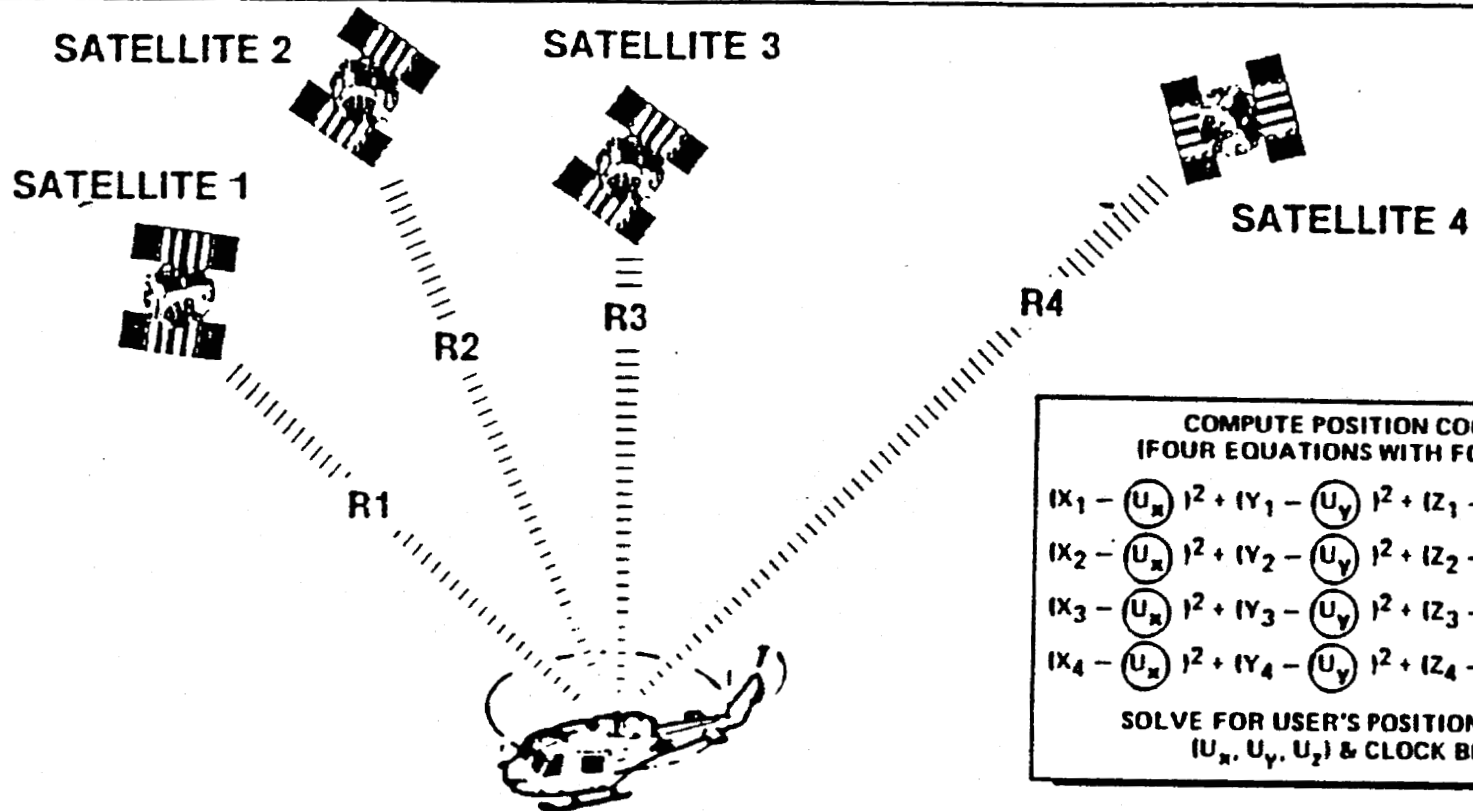
# Broadcast Signal

- Satellites broadcast on L1 (1575.42 MHz) and L2 (1227.60 MHz)
- "Coarse Acquisition" C/A code phase modulated on L1 (at 1.023 MHz)
- "Precise" P code phase modulated on L1 and L2 (at 10.23 MHz)
- 50 bit/second data stream on L1 and L2

# Navigation Message

- **Clock/atmospheric corrections**
- **Satellite ephemeris**
- **Spacecraft health**
- **Less precise constellation information**

# NAVIGATING WITH THE GPS



**COMPUTE POSITION COORDINATES  
(FOUR EQUATIONS WITH FOUR UNKNOWN)**

$$(X_1 - U_x)^2 + (Y_1 - U_y)^2 + (Z_1 - U_z)^2 = (R_1 - C_B)^2$$

$$(X_2 - U_x)^2 + (Y_2 - U_y)^2 + (Z_2 - U_z)^2 = (R_2 - C_B)^2$$

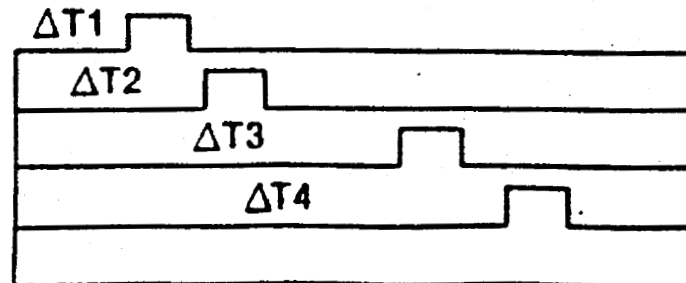
$$(X_3 - U_x)^2 + (Y_3 - U_y)^2 + (Z_3 - U_z)^2 = (R_3 - C_B)^2$$

$$(X_4 - U_x)^2 + (Y_4 - U_y)^2 + (Z_4 - U_z)^2 = (R_4 - C_B)^2$$

**SOLVE FOR USER'S POSITION COORDINATES  
( $U_x, U_y, U_z$ ) & CLOCK BIAS ( $C_B$ )**

COMPUTE FOUR PSEUDO-RANGE VALUES

TIME SIGNALS  
TRANSMITTED  
BY SATELLITE



$$R1 = C \times T1$$

$$R2 = C \times T2$$

$$R3 = C \times T3$$

$$R4 = C \times T4$$

(C = SPEED OF LIGHT)

# Spacecraft Applications of GPS

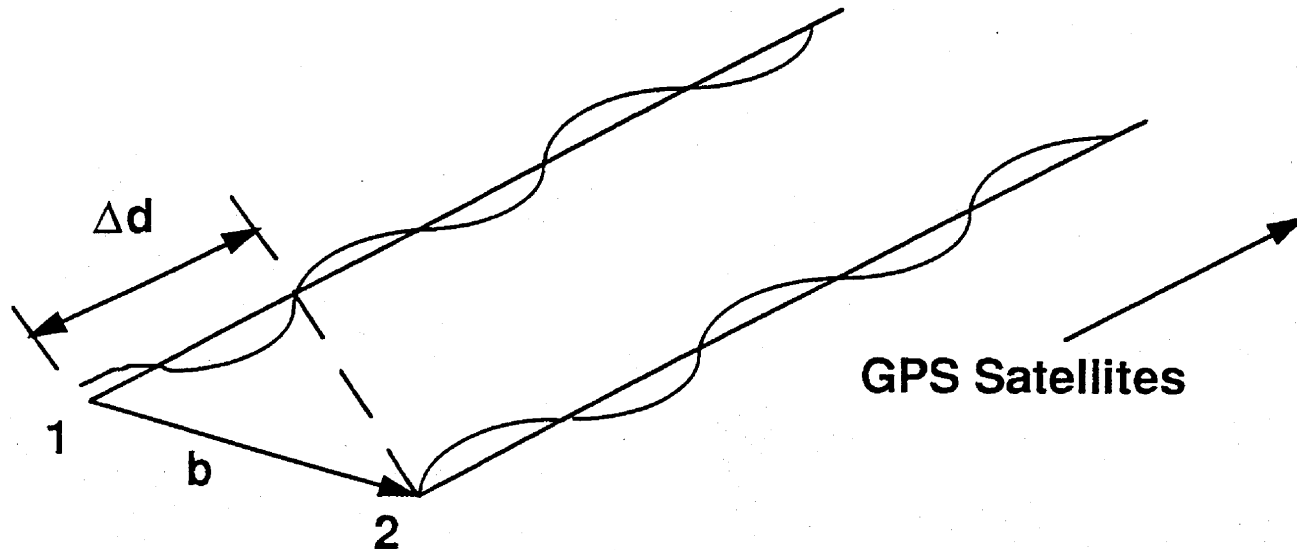
- **Absolute navigation**
- **Attitude determination**
- **Differential/relative navigation**

# **Spacecraft Using GPS**

## **(Absolute Navigation)**

- **TOPEX/Poseidon, EUVE**
  - ground tracking stations
  - post-processing for orbit determination
- **Landsats 4, 5 (real-time)**
- **Space shuttle orbiter (experimental data collection)**
- **Military satellites**

# Attitude Determination



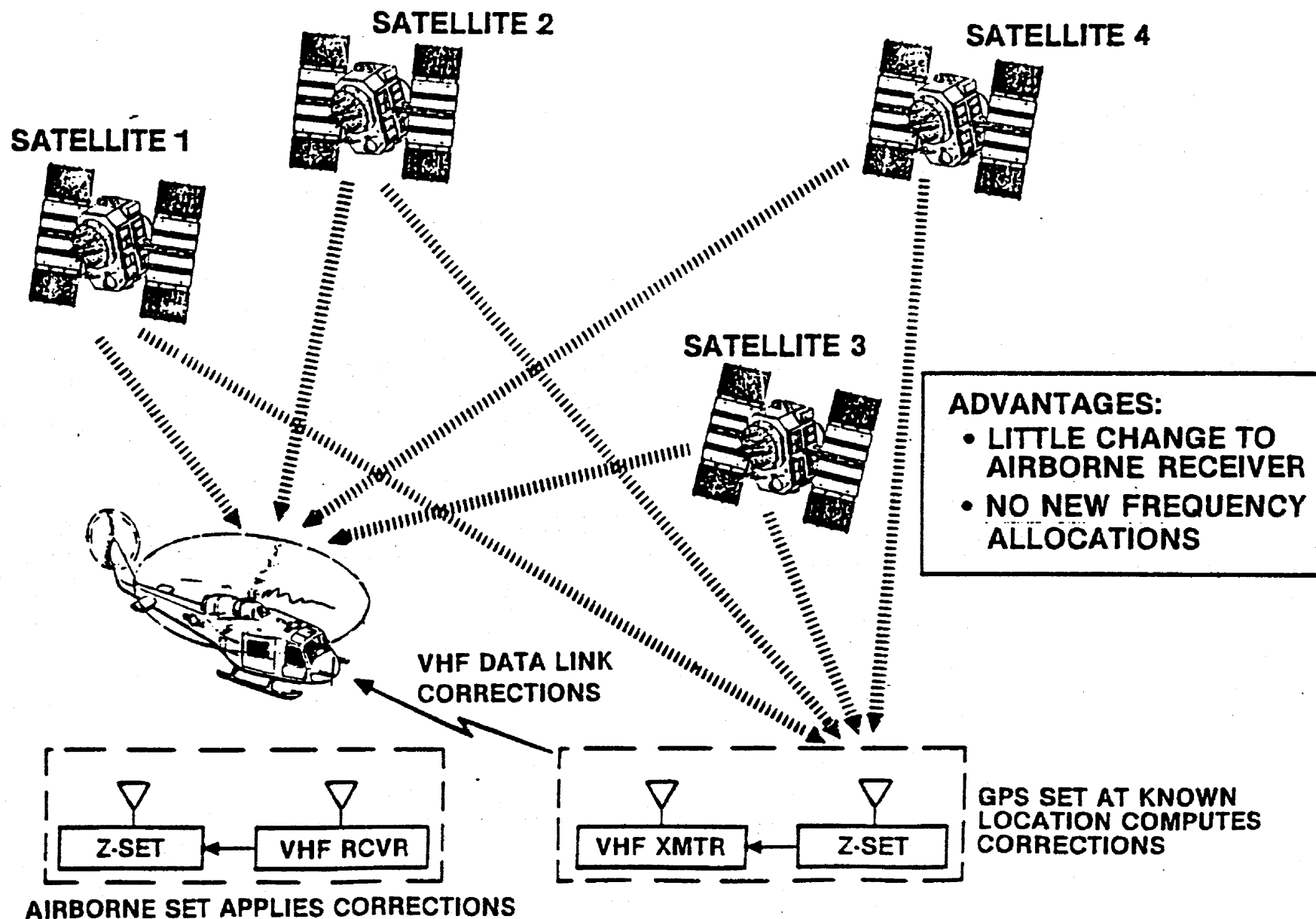
Based on interferometry - two or more receivers tracking same wave and measuring phase difference between them to get orientation of receivers



# Attitude Determination

- **Purcell et al**
  - non-real-time heading and pitch determination
  - $<1$  mrad over 23 m baseline
- **Ohio University**
  - DC-3
  - 1 mrad for 10 m baseline in real-time
  - wing flexing also measured
- **Stanford University**
  - Piper Dakota
  - 0.1 deg accuracy over 3 m baseline in real-time
  - wing flexing also measured
- **RADCAL satellite (Air Force satellite)**

# DIFFERENTIAL GPS: DATA LINK TYPE



# Differential GPS Applications

## Accuracy

### Differential

- Surveying (mm - cm)
- Instrument approaches (< 0.1 m)
- Harbor navigation (< 2.0 m)

### Relative

- Proximity operations (???)

# Summary

- **Absolute spacecraft navigation with GPS has been done with post-processing and in real-time**
- **Differential/relative navigation with GPS has not been attempted in space; aircraft have demonstrated sub-decimeter accuracy in real-time**
- **Attitude determination with GPS has been demonstrated in real-time on small aircraft and is currently being implemented on RADCAL satellite**

# Langley Activities with GPS

- **TSRV Aircraft (Boeing 737) Autoland Research**
  - Honeywell: single frequency, 2 channel receivers, INS integration, 5-7 m difference with laser tracker
  - Ohio University: dual frequency, 12 channel receivers, carrier phase tracking, < 0.1 m difference
  - Wilcox: code phase, carrier aiding, 1-2 m accuracy anticipated
  - Allied Signal/Navsys: data collection with pseudolites and carrier phase tracking
- **General aviation studies**
- **F-16 trajectory reconstruction**

# Concluding Remarks

- **Non-space GPS applications are exploding in civilian and military sectors**
- **Use of GPS in space is slowly increasing**
- **NASA LaRC has experience planning and supporting GPS research and applications for aircraft ==> can leverage off this experience for space-based proximity operations GPS applications**



# Introduction to **CTA Launch Services**

September 1993

- **Introduction to CTA**
  - **CTA Systems Group**
  - **Defense System Inc.**
  - **CTA Launch Services**
  
- **Products & Services**
  - **ORBEX Launch Services**
  - **PONY EXPRESS™ Turnkey Services**
  - **Engineering Services**



## **Company Overview**

## **Background on CTA**

- **Founded in 1979**
- **Consistent 30-50% annual growth since founded**
- **Projected 1993 Revenues of \$150 M**
- **CTA has completed over \$700 M of Government Contracts**

## **Key Business Areas**

- **Air Traffic Control**
- **Government Services (C<sup>3</sup>I)**
- **Small satellites**
- **Communications**
- **Avionics Systems**
- **Simulation & Training**
- **Small Launch Vehicles**
- **Environmental Monitoring**

## **Subsidiary Companies**

- **Defense Systems Inc.**
- **CTA Launch Services**  
(formerly International MicroSpace)



LAUNCH SERVICES

## CTA Organization

\$ 133 Million in revenues, 1992  
1200 Employees  
Headquarters in Rockville, MD  
Acquired Defense System Inc. in July 1992  
Acquired IMI in August 1993

### CEO & PRESIDENT

C. E. Velez, CEO

G. Wagner  
Chief Financial  
Officer

B. A. Claussen  
Deputy

B. Ramsey  
Business Development

### SYSTEMS GROUP CHIEF OPERATING OFFICER

M. Titland

G. Sebestyen, Deputy  
Engineering

K. Davis, Deputy  
Business Management

### SERVICES GROUP CHIEF OPERATING OFFICER

R. McMillan

T. Piddington, Deputy

#### DSI

G. Sebestyen

- Space Product Development
- Remote Sensors
- Commercial Communications

#### SIMULATION SYSTEMS

W. Keith

- Radar/NAV Trainers
- Glass Cockpits
- Part Task Trainers

#### TECHNOLOGIES

L. Capots

#### CTA LAUNCH SERVICES

B. Schwartz

- ORBEX Launch Services
- Pony Express
- Engineering Services

#### AVIONICS SYSTEMS

J. Hitchcock

- NWC Omnibus Engineering
- Avionic & Weapons Integration
- OFP Maintenance

#### C I & SPACE

R. McMillan

- USAF Omnibus Engineering
- NASA, USAF Space Systems Engineering
- FEMA Systems

#### AIR TRAFFIC SYSTEMS

M. Phillips

- FAA Systems Engineering Test & Evaluation

**DSI has built and launched 19 satellites which have worked successfully in space.**

**STACKSAT**  
Apr 90  
(ATLAS-E)

**ISES**  
Jun 91

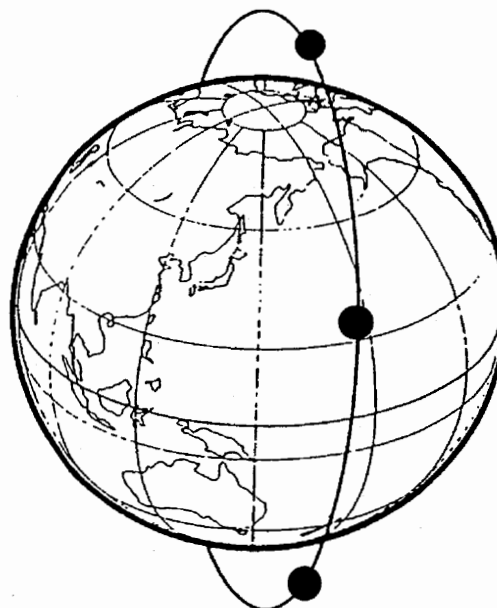
**MACSAT**  
May 90  
(SCOUT)

**TERCEL**  
Apr 90  
(PEGASUS)

**RADCAL**  
Jul 93  
(SCOUT)

**MICROSAT**  
Jul 91

**CRO**  
May 91  
(SHUTTLE)



### **Objective**

**Develop cost effective space transportation for small satellites and provide turnkey space based services**

### **Key Principles**

- **Reduce Lead Time and Mission Life Cycles**
- **Put Individual Customers in Control over Mission**
- **Minimize Development Time and Cost to the Customer**
- **Simplify and Streamline Operations**
- **Develop Systems that Meet Mission Requirements within Budget Constraints**
- **Do Business Differently - "Build a Little, Test a Little"**

### **Implementation Strategy**

- **Implement thru Strategic Relationships**
- **Maximize Off-the-Shelf Flight-Proven Technology**
- **Minimize Infrastructure Development**
- **Capitalize on Synergy Among Products & Services**
- **Focus on Reliability**
- **Achieve Goals thru Continuous Improvement**

### Need for Dedicated Launcher for MicroSatellites

- Users have to Piggyback, Share a Ride or Buy an Oversized Vehicle
- Only One Operational Vehicle in the 400-1,000 lb. Class

### Need for Affordable Launch Services

- Fit within reduced Budgets
- Matches Payload Size/Cost with Launch Service Cost
- Need to drive launch costs to a \$6M - \$8M level

### Need for Alternate Source

- Costs have Grown from \$6.5 m to \$14.0 m in three years
- Current Supplier has Large Backlog (Air Force, NASA, Commercial)
- Risk of Delay if Failure or Anomalies Occur without Alternate Source

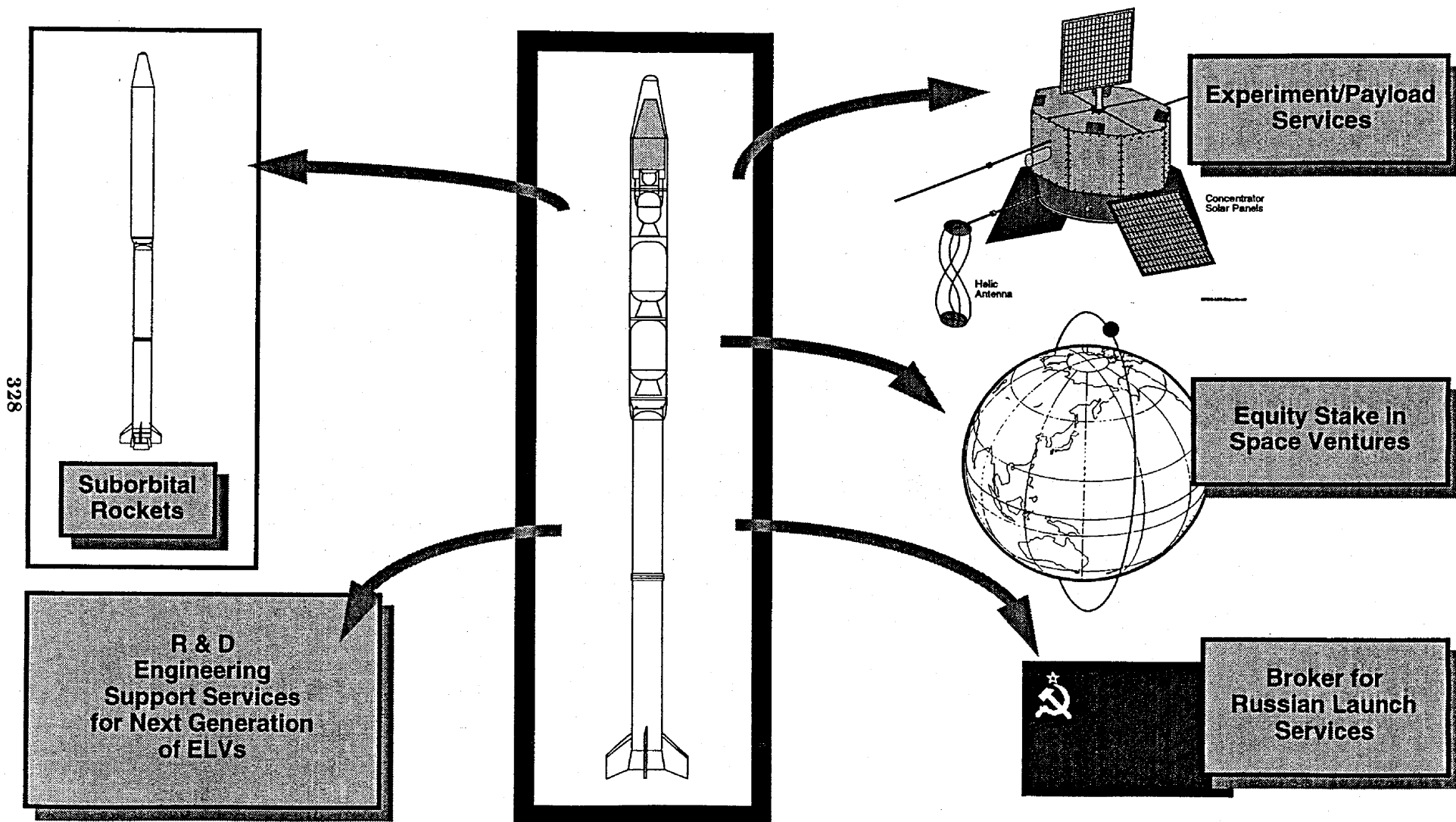
### Need for Turnkey Services

- For Customers only Interested in the End Game; Not developing the Infrastructure to get there
- Modular Components with Standard Interface can Lower Costs and Reduce Development Schedules
- Enhances Responsiveness

Two significant events have allowed us to transition from an entrepreneurial start up company to a viable contender in the small launch services business.

1. ***Currently Under Contract*** - In July 1992 IMI was awarded a contract with Ballistic Missile Defense Organization (BMDO) to develop and launch a 450 lbm satellite to a 300nm orbit with an initial launch date of September 1994. Total contract value including options is \$125 million.
2. ***Acquired by CTA Incorporated*** - a \$150 million engineering services and high technology systems firm. In acquiring IMI, CTA now has the capability to provide fully integrated, end-to-end system solutions to customers requiring data services, information products, satellites, ground stations, ground sensors and launch services. This new marriage maintains the flexibility and responsiveness of a small business while having the vast resources and expertise inherent in a large organization.

With a government contract and a parent company committed to establishing the lowest cost and greatest reliability launch service, we will evolve our family of launch vehicles to achieve reliability (96%), schedule (award to launch -15 months ) and cost (\$5 million) goals.





**CTA Launch Services**  
**Products & Services**

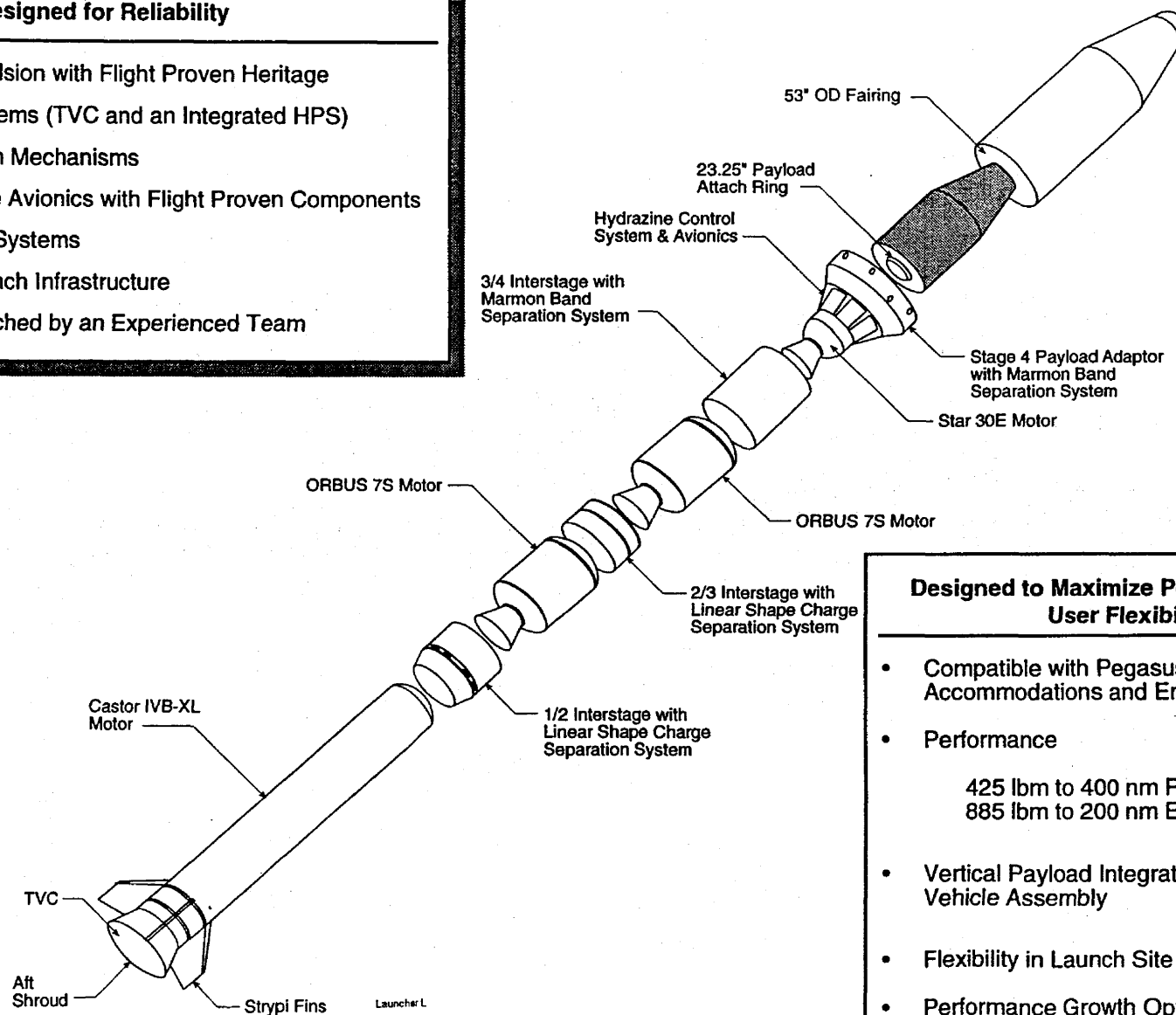
**ORBEX**  
**LAUNCH SERVICES**

**PONY EXPRESS™**  
**TURNKEY SERVICES**

**ENGINEERING**  
**SERVICES**

## Designed for Reliability

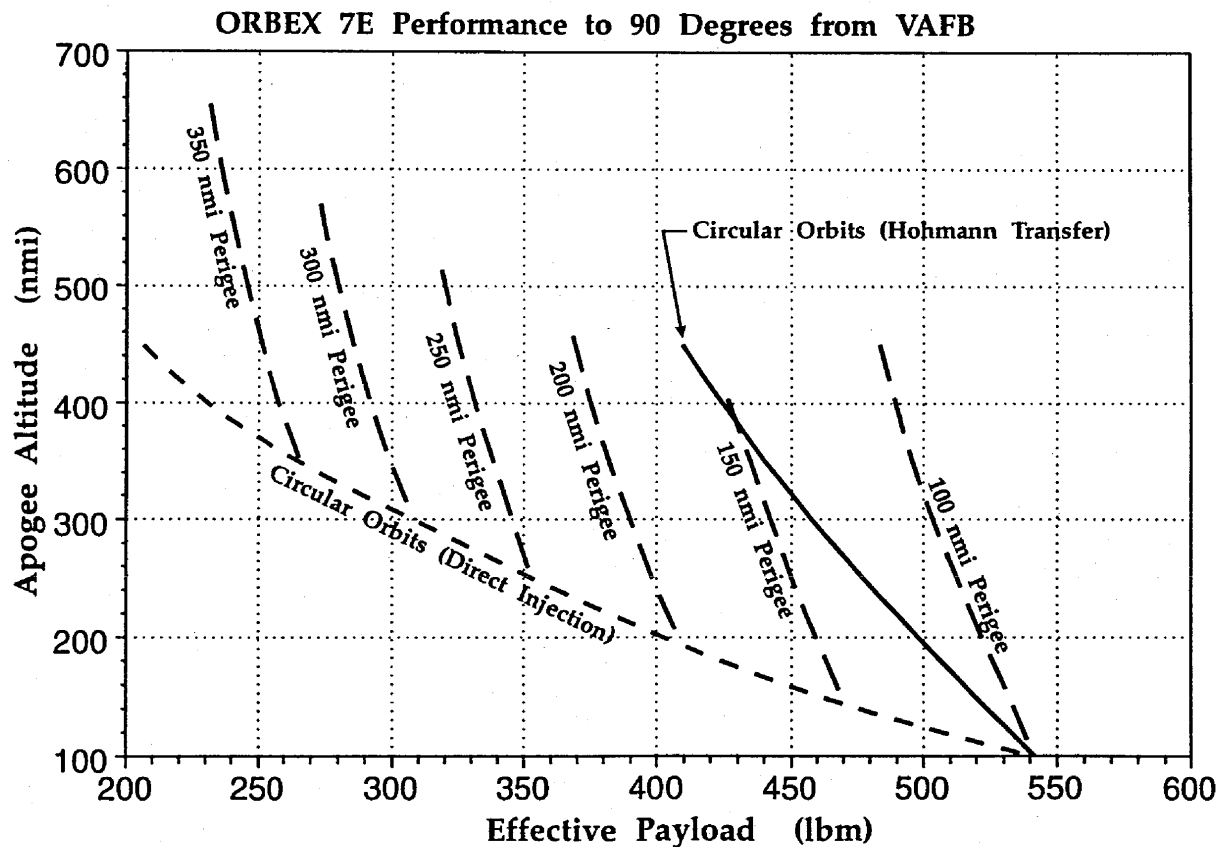
- 4 Stage Solid Propulsion with Flight Proven Heritage
- Simple Control Systems (TVC and an Integrated HPS)
- Common Separation Mechanisms
- Integrated 4th Stage Avionics with Flight Proven Components
- Simple Mechanical Systems
- Use of Existing Launch Infrastructure
- Designed and Launched by an Experienced Team



## Designed to Maximize Performance and User Flexibility

- Compatible with Pegasus Payload Accommodations and Environments
- Performance
  - 425 lbm to 400 nm Polar
  - 885 lbm to 200 nm Equatorial
- Vertical Payload Integration and Horizontal Vehicle Assembly
- Flexibility in Launch Site Selection
- Performance Growth Options

331



**Payload to orbit**

425lb to 400nm Polar

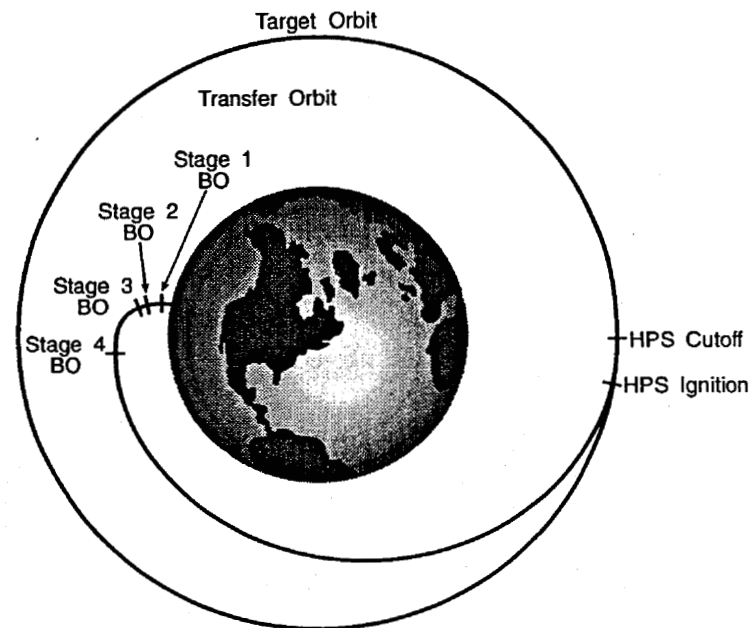
885lb to 200nm Equator

**Insertion Accuracy  $\pm 5$  nm**

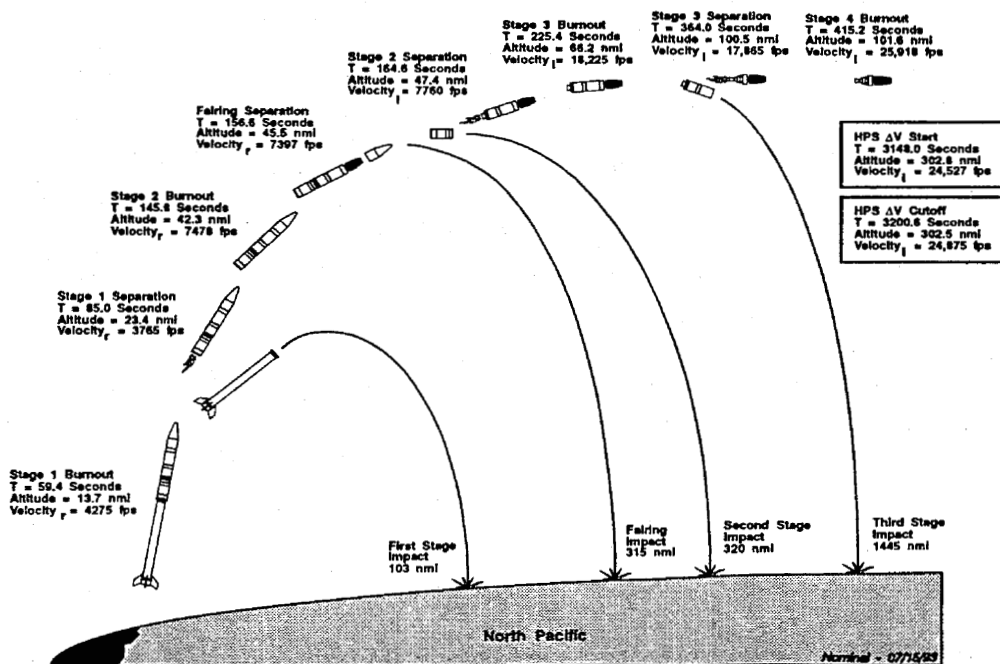
**Inclination Accuracy  $\pm .1^\circ$**

## Control Strategy

- 3-axis Stabilization During all Phases of Flight
- Stage 1 Burn - TVC for Yaw & Pitch, HPS for Roll Control, Fins for Stabilization
- Stage 2, 3, 4 Burn & Coast - HPS for Yaw, Pitch & Roll Control



332

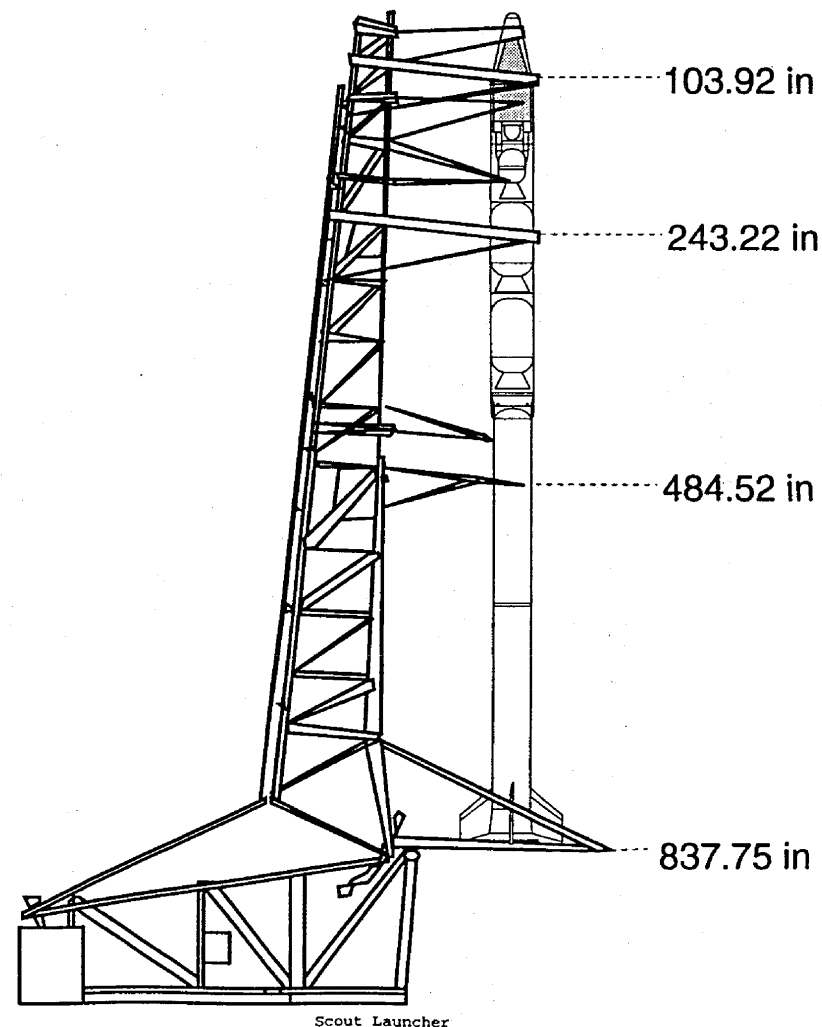
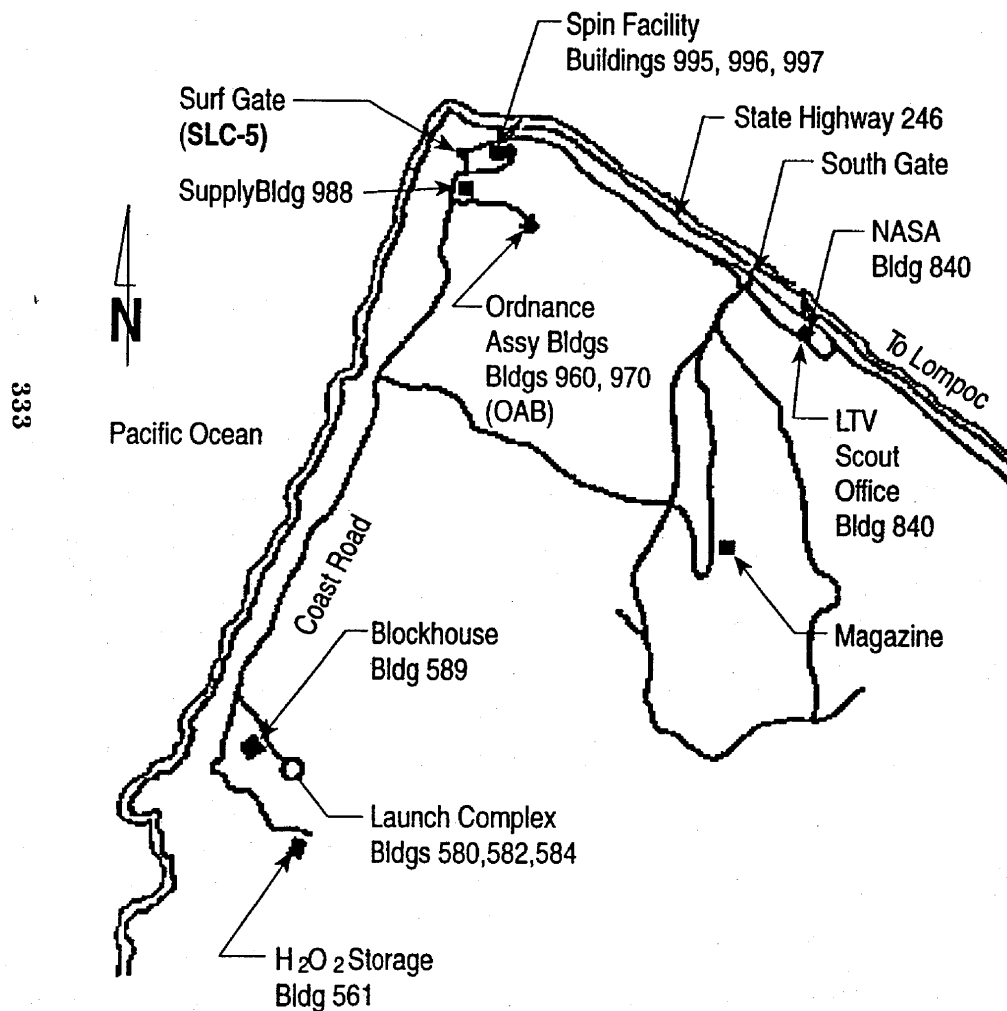


## Guidance Strategy

- Fly Nominal Trajectory to a Hohmann Transfer Orbit (100 nm by Final Destination Orbit)
- Use HPS to Circularize Orbit

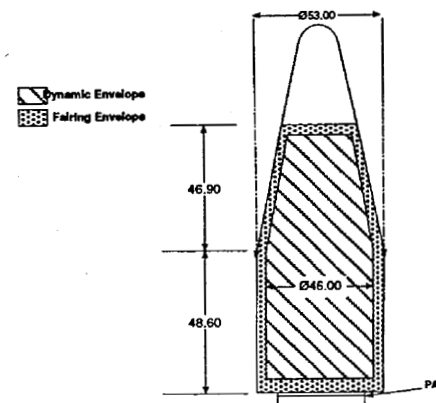
## VAFB – SLC-5

## Scout Launcher

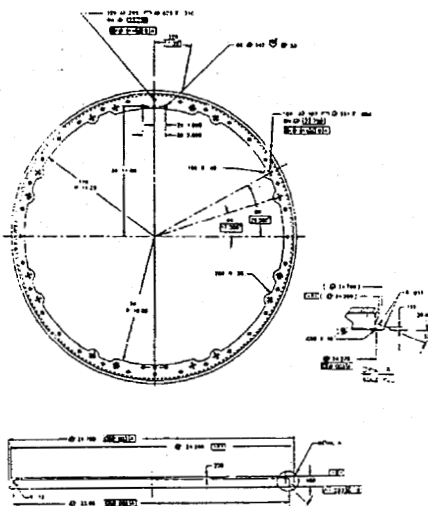


## Designed to be Compatible with Pegasus

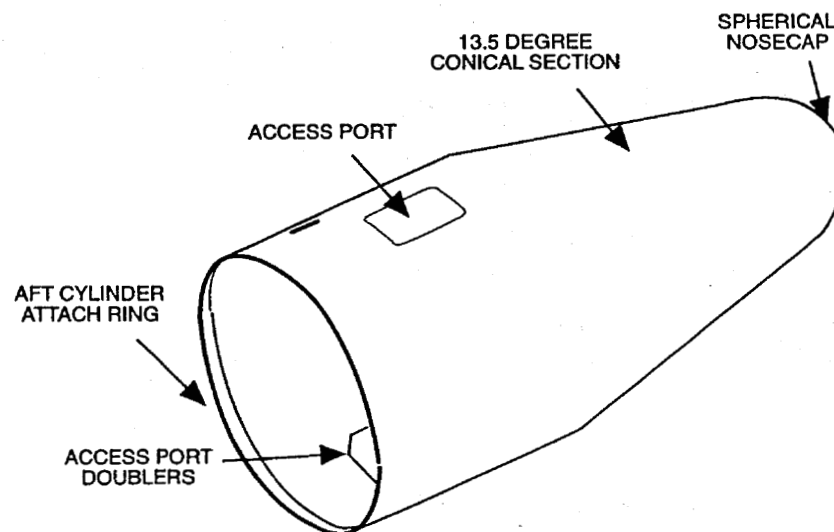
- Same 46" Dynamic Envelope
- Same 18 & 42 Pin Electrical Connector
- Same 23.25" Payload Attach Bolt-on Pattern
- Same Fairing Payload Access Door Position
- Similar Flight Environments



46" Dynamic Envelope

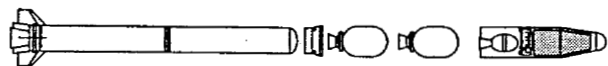


Payload Attach Ring with 23.25" Bolt Pattern



53" Forward Ejecting Fairing

## ORDNANCE ASSEMBLY BUILDING

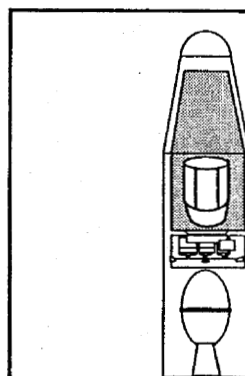


Motors and Hardware Receiving and Inspection

Payload 4th Stage Horizontal Mating to ORBEX on Transport



Vehicle System/Subsystem Test and Check Out, Assembly on Transporter, Mission Simulation and Transport to Launcher

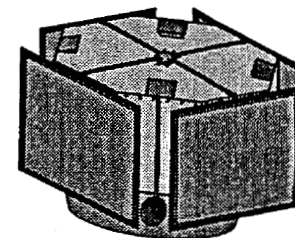


Upper Stage, Fairing & Payload Vertical Integration

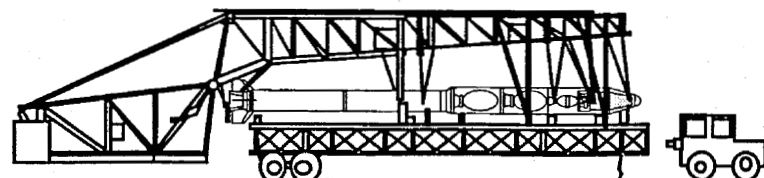
## SPACECRAFT INTEGRATION BUILDING

**Payload**

- Receiving
- Assembly
- Test & Checkout

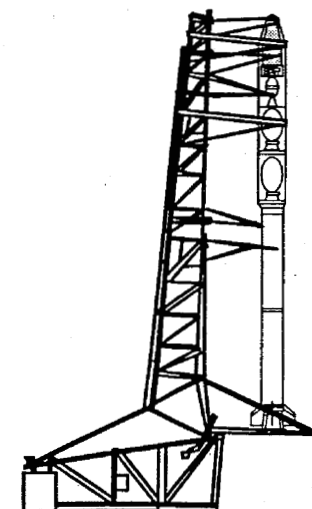


335



Install Vehicle On Launcher

Perform Mission Simulation Test, Conduct Post-Test Evaluation, Preps For Final Countdown, and Launch

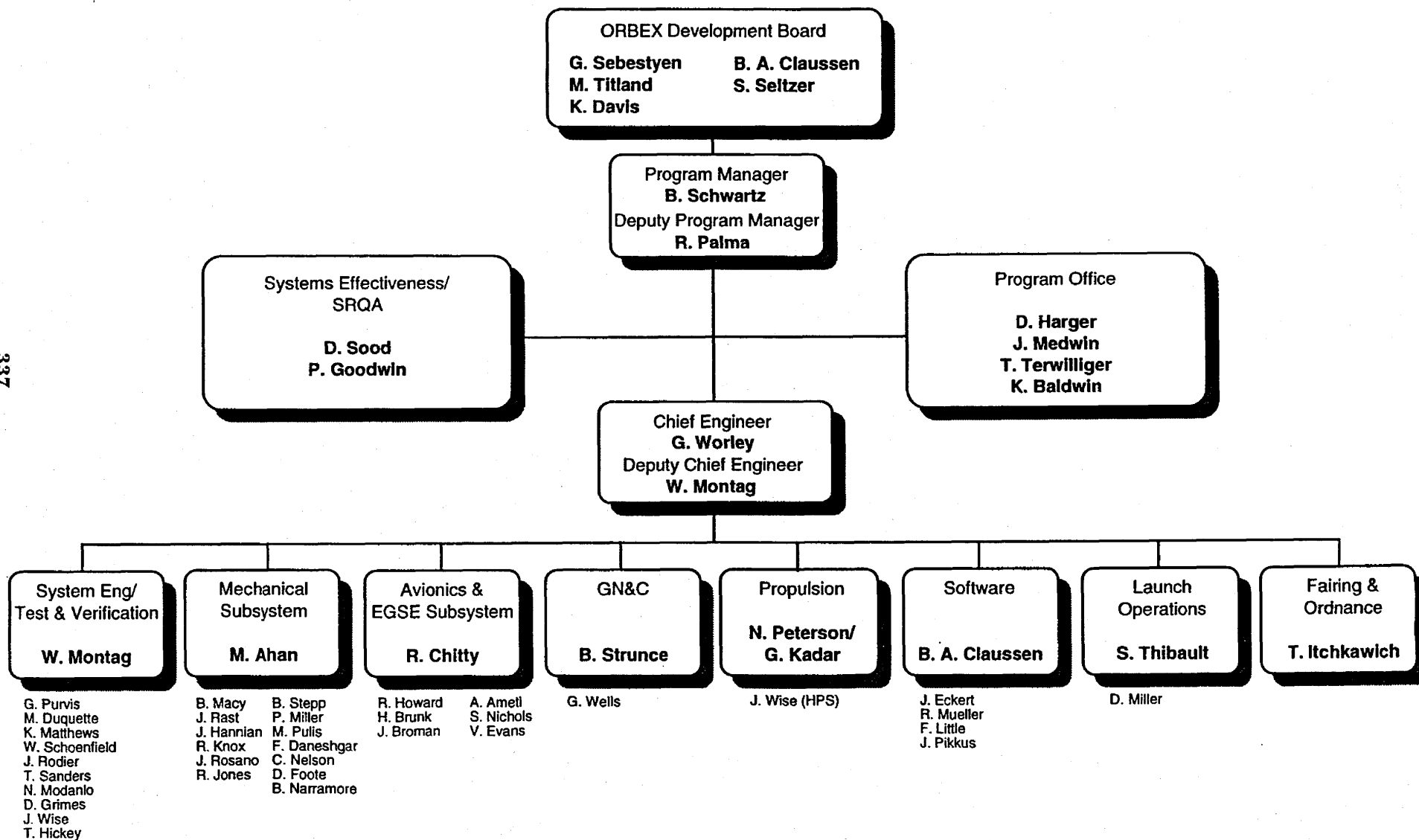


## MSTI-6 Mission Requirements

	Contract Revised Requirements*
<b>Performance</b>	Spacecraft Weight: 450 lbs. Spacecraft Size: 46-inch Dynamic Envelope Orbit Inclination: 75 +/- 2 degree Orbit Altitude: 250 nm (min. perigee)
<b>Mechanical Interface</b>	46-inch min. Dynamic Envelope Compatible with Pegasus 23.25 Bolt Pattern
<b>Electrical Interface</b>	2 Timing Events (10 second max, 10 msec accuracy) Pegasus Equivalent Connectors 2 Pyro Event (5As, 75 msec)
<b>Environments</b>	Thermal: <150° F Venting Rate: <1.76 psi/sec Shock: <2,500g Acoustic: <133 dB Vibration: <.03g/Hz Acceleration: ≤10g
<b>Launch Operations</b>	Launch Date: Sept 1994 Launch Site: VAFB; SLC-5

\*Per MIWG #1 & #2 and Modification #3





### Core Team

**IMI/CTA/DSI**

**Program Management, System Integration, Mechanical & Electrical Design, Mission Integration, Test & Verification**

**Conatec**

**System Engineering, Mission Analysis, Propulsion/Ordnance Engineering, Launch Operations & Mission Integration Support**

**FAI**

**Mechanical Design & Analysis, Thermal Analysis, Launch Operations Support**

### Major Suppliers

**Thiokol**

**Stages 1 & 4 Motors, Safe & Arm Units, Conical Shape Charges**

**RSLP/Hughes/UTC**

**Stage 2 & 3 Motors**

**Litton**

**Flight Computer and Inertial Measurement Unit**

**IDEA/IAI**

**Fairing**

**Logicon Control Dynamics**

**GN&C Flight Software**

**Sandia Labs**

**Navigational Flight Software**

**Sun Country**

**Fins**

**AydinVector/Multiple**

**Avionics**

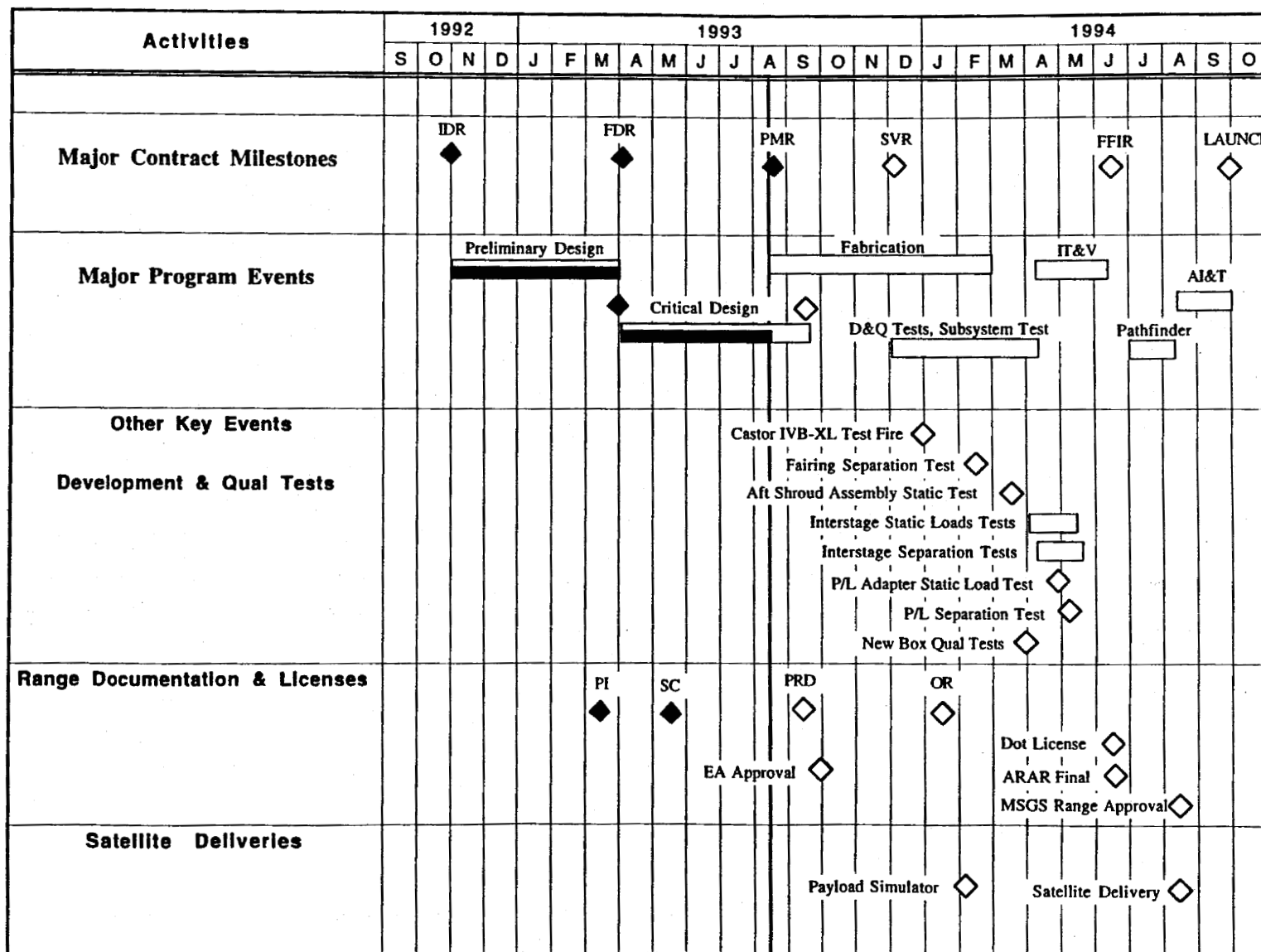
**Ensign Bickford**

**Ordnance**

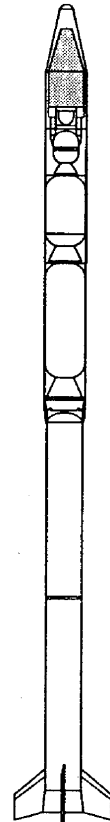
**Rocket Research**

**Hydrazine Propulsion System**

# Program Schedule

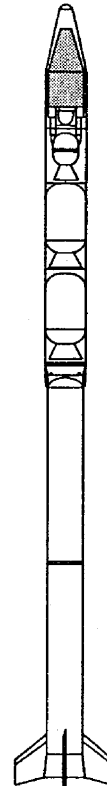


340



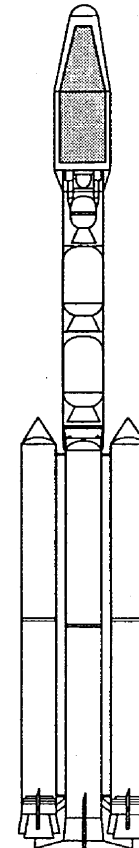
**Ballistic Missile Assets**

Stage 0	
Stage 1	Castor IVB-XL
Stage 2	SR-19
Stage 3	SR-73
Stage 4	Star 30E
	Liquid Trim



**ORBEX 7E**

Castor IVB-XL
Orbus 7S
Orbus 7S
Star 30E
Liquid Trim



**Growth Option**

2 Castor IVB-XLs
Castor IVB-XL
Orbus 7S
Orbus 7S
Star 30E
Liquid Trim

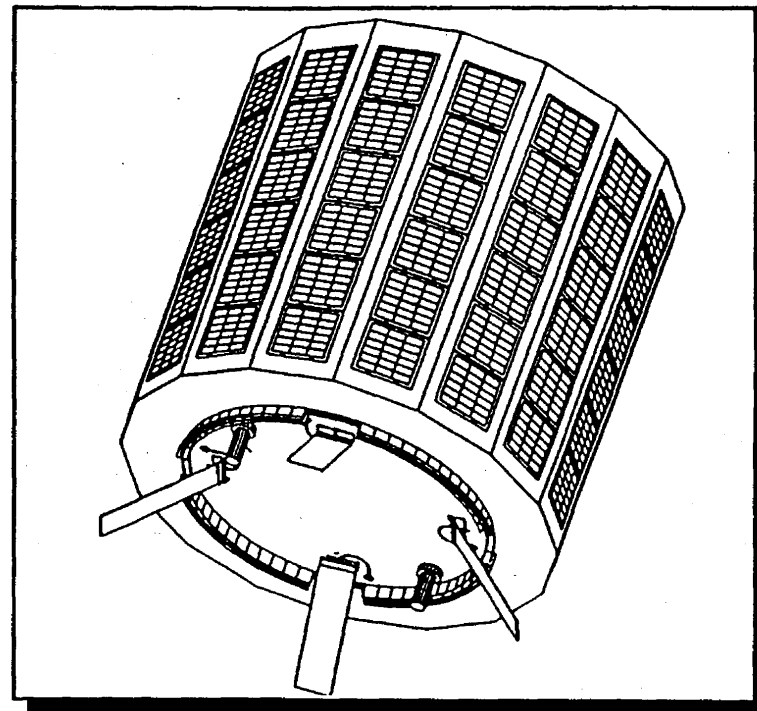
- **Successful Contract Performance**
- **Lower Cost/System**
  - **Launch Costs**
  - **Total Life Cycle Costs**
- **Responsiveness to Customer Community**

**Markets and Applications Concept:**

- Customer identifies experiments or sensor package needing access to space
- Sensor bolted on to standard DSI Satellite Bus and integrated into ORBEX launch vehicle
- Ground station provided to monitor spacecraft and collect data
- Service offered at a fixed price (\$13-15M)

**Benefits:**

- Dedicated launch where customer has control
- Customer can focus on sensor or payload application
- Reduces development time and resources required
- Access to orbit in 12-15 months
- Customer does not pay the development costs



**Satellite Characteristics**

- Cylinder: 30" by 60"
- Payload Weight: 250-400 lbs
- Stabilization: 3 axis with five degree accuracy
- Power: 60 watts average up to 200 watts

- **Constellation Communications, Inc.**
- **Environmental Data Satellite (EDS)**
- **Worldview**

### Business Opportunity:

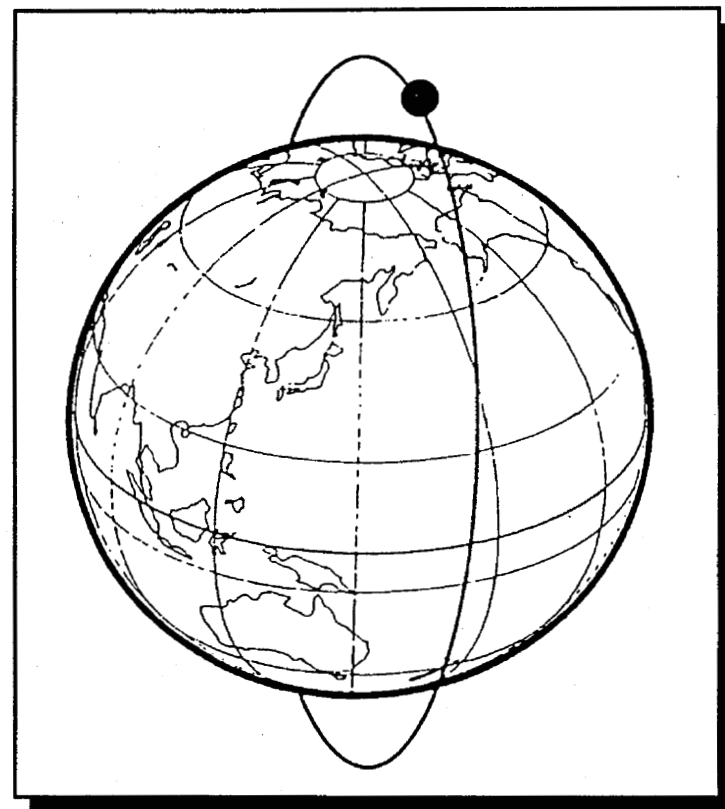
Environmental Monitoring and Remote  
Data Collection & Dissemination

### Technology Partners:

CTA Launch Services  
Defense Systems, Inc.  
Geophysical Institute/Univ. of Alaska

### Markets and Applications

- Pollution Monitoring (Air & Water)
- Forest Fire Detection
- Oil Spill Clean-up support
- Volcanic Monitoring for Airlines
- Fish Location
- Pipeline & Oil Well Monitoring
- Emergency Location & Communications
- Pollution Site Remediation
- Wildlife Tracking
- Scientific Data Collection



### Customers:

Industries (US & Int'l)  
US Federal Government  
State Government  
Foreign Governments



## **Business Opportunity:**

Personal Communications via LEO  
Satellites

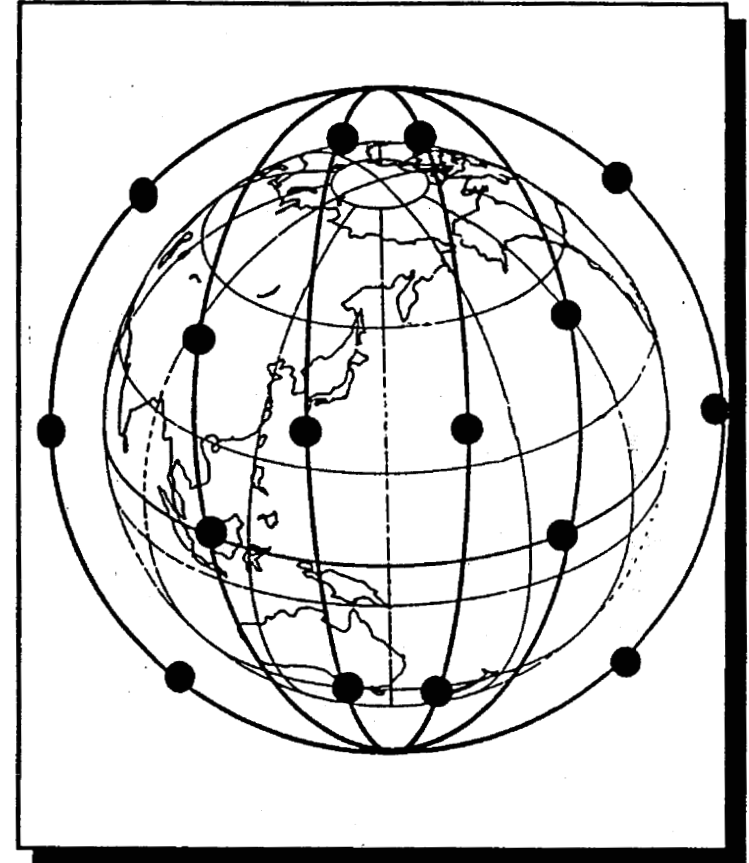
## **Technology Partners:**

Defense Systems, Inc.  
Pacific Communications Sciences, Inc.  
CTA Launch Services

## **Markets and Applications**

Remote Data Collection  
Voice/Data/Fax  
Specialized Networks

- One of only 5 companies eligible for FCC license
- Lowest cost, lowest risk implementation approach using existing technology
- Offering best opportunity to influence technology and market



- CTA owns 36% of CCI
- Has exclusivity to provide launch services

### **Payload Integration Services**

- Mission Analysis
- Satellite/payload integration
- Launch Support & Test

### **Requirement Definition & Analysis**

- Flight Performance
- Trade Studies
- Subsystem Feasibility
- Telemetry & Power
- Spacecraft Command & Control
- Post Flight Analysis

### **Hardware Design & Fabrication**

- Flight Systems Avionics
- Ground & Flight Software

### **Vendor Monitoring & Acceptance Test**

- Propulsion
- Ordnance
- GN&C Hardware

- **Founded Jan-92; commercial remote sensing firm**
  - CEO: Douglas Gerull, former Executive VP of Intergraph's Mapping & GIS Division
  - Chairman & CTO: Walter Scott, former head of Lawrence Livermore National Laboratory's Brilliant Pebbles program
  - Backed by Silicon Valley venture capital (TVI; Burr, Egan, Deleage)
- **Licensed Jan-93 by U.S. Commerce Department to operate a private remote sensing satellite system**
  - Launches planned for 1995-1996
  - Commercial markets: mapping, GIS, environment, ...
- **Signed strategic partnership agreement with CTA May-93**
  - DSI will build WorldView satellite buses
  - CTA will invest in WorldView



# **SESSION III**



# **Summary of the SELV-Based In-Space Operation Workshop**

## **October 18-19, 1993**

### **Hampton, VA**

#### **SESSION III**

##### **Bill Hohwiesner, Fairchild Space**

Mr. Hohwiesner began with a review of Fairchild's work in the in-space servicing area. This included development of tools and related technology for a variety of missions. Examples given were the interfaces placed on the Extreme Ultraviolet Explorer (EUVE) to enable a future servicing mission, the Solar Max servicing by Shuttle astronauts and the planned Hubble Space Telescope (HST) servicing mission.

Mr. Hohwiesner first reviewed the Solar Max mission, originally launched by the Shuttle in 1980 and then serviced in 1984. He described how the spacecraft was designed for an STS retrieval and how the subsystem modules were designed for on-orbit removal and replacement. For this mission, Fairchild developed the Module Service Tool, which is inserted into a latch on the modules to simultaneously remove the bolt holding them to the spacecraft bus and disconnect their electrical interfaces.

He later discussed on-orbit servicing by astronauts of a spacecraft not originally designed for servicing. In this mission, the thermal blanket was cut and an electrical box was replaced. A similar operation was later demonstrated on the ground using teleoperation.

Mr. Hohwiesner then discussed the Explorer class of spacecraft (such as EUVE). These are designed so that every module could be replaced without requiring EVA. Design details include:

- Removable high gain antenna.
- Removable main spacecraft modules.
- The Platform Equipment Deck (PED) contains six modules which can be removed on-orbit.
- The payload module is removable by removing three Acme screws which can be reached when the spacecraft is grappled by the RMS and docked to the shuttle.

He next described their work on the HST servicing with GSFC. This involved modifying the flight support system and building an ORU carrier and a Solar Array carrier. They also built a servicing tool which was miniaturized so that it could be placed on the end of the RMS arm.

352 Fairchild also has a "Servicer Aid" which is currently in validation. It can be mounted in the aft cargo bay of the shuttle and contains a 6 DOF force reflecting master arm. This arm can generate up to 500 lbs in zero gravity. The test article weighs 350 lbs and their goal is to have this reduced to 150 lbs plus 50 lbs for the electronics. This is completing flight qualification for the second HST servicing mission. The master arm will be mounted in the aft cargo area and reflects up to 21 lbs of force back to the operator. The slave arm can be adjusted in size depending upon the application. The arm lengths are interchangeable.

Mr. Hohwiesner stated that servicing could be a cost effective way of extending spacecraft life. The high cost of the servicing missions in the past was the result of the high costs of using the Space Shuttle. Fairchild has demonstrated teleoperated servicing operations in the lab which they believe offers the potential for low-cost spacecraft life extension

In the area of GPS, Mr. Hohwiesner explained that the RADCAL mission was using a \$12,000 Trimble receiver (as compared to the \$500,000 one on TOPEX) and that Fairchild is going to demonstrate relative navigation with GPS on shuttle mission STS-69. This is to be complemented by the proximity sensors developed by Tom Bryant's branch at MSFC. This mission will demonstrate station keeping around a three-point docking adapter.



A characteristic of many potential servicing missions is a failure to reach proper orbit. On this note, Mr. Hohweisner described a device developed by Thiokol under an IRAD to re-ignite a failed apogee kick motor. This device has been demonstrated.

Mr. Hohweisner provided further detail about EUVE apropos a servicing mission. An Earth-Pointing attitude was studied for the fluid resupply missions. They have shown that the EUVE ACS can maintain attitude control in a single mode through the docking maneuver with up to a 1000 lb chase vehicle.

The 12 channel GPS system can be used to navigate within 500 meters before the laser sensors take over.

Mr. Hohweisner then discussed cost estimates for such a mission. Putting it together within a year would be difficult ; 1.5 years is more likely. The cooperative target servicer could easily be built for \$40 million or less. Probably, it could be built for less than \$30 million. The non-cooperative servicing mission would be in the \$40-50 million range, the main driver for this mission is the cost (at least \$5 million) for the high gain antenna. This excludes the launch vehicle costs.

#### Prof. Dave Akin, University of Maryland

Prof. Akin serves on the NASA telerobotic working group and presented his work and the status of the Ranger mission.

Prof. Akin's research in telerobotics began when he was at MIT. Under a grant from MSFC, his group conceptually designed the HFFT (Hybrid Free Flying Tele-robot) which provided a life support capsule for an astronaut who could operate the robotic systems on its exterior.

In 1990, Prof. Akin moved his research to the University of Maryland. A neutral buoyancy facility consisting of a 50 foot diameter water tank was made available there for his research.

At this point, the concept for the Ranger mission was formulated. It is designed to have the same servicing capability as an astronaut in a pressure suit and would be constrained to fit within the shroud of the Pegasus launch vehicle.

Following this initial feasibility study, Prof. Akin's group determined that this mission was possible as a flight experiment and set the ground rules for a flight demonstration to be flown in the first quarter of 1996 at a budget of less than \$ 6 million.

The objective of the flight experiment is to correlate experience in the neutral buoyancy facility with actual space operations.

As a high risk mission, Prof. Akin is willing to accept mission failure. For this reason, the tests will be phased, starting with simple operations which have lower inherent risk and then progressing to more difficult tests.

Prof. Akin then went into more detail about the design of the Ranger spacecraft. The section where the manipulators are attached is designed to minimize the frontal area so as to reduce the potential for interference with motion of the arms. The overall vehicle is sized to be roughly Human scale. Two dexterous manipulators are provided. Prof. Akin expanded on the studies showing that one-handed EVA is severely limited in its capabilities. Vision is provided by a stereo camera which can be maneuvered around the vehicle and its target.

More details were given on Ranger. The total mass was about 1000 lbs. Reaction wheels and batteries were the main drivers in mass. Approximately 400 lbs was allocated to computers and the manipulators. The power system had a 6kW peak capability with 1.5 - 2 kW average.

Ranger is planned to be launched into a high eccentricity orbit which would give four passes per day in which to communicate with the vehicle. It will be launched as a secondary payload with LAGEOS into a 5900 km altitude orbit.

The minimum criteria for mission success would be data on manipulator behavior in orbit. Further goals are to demonstrate some specific operations planned for servicing missions. The spent booster stage from Ranger's launch will be used as its target.

The end effectors are designed to be interchangeable. Approximately 20 lbs of force and 20 ft-lbs of torque can be applied through the end effector. The spacecraft will make a rigid grapple with the target using a passive grapple mechanism. The grapple is the only mechanism on Ranger which has friction brakes. The kinematics are such that no singularities are present within the workspace of the manipulators. Drive electronics for each joint are co-located with the drive motors themselves.

Prof. Akin then outlined some typical satellite servicing tasks to be demonstrated. These include: target acquisition, grappling (using a device designed for the EVA handrail), and refueling.

355 The Ranger mission is scheduled to last 30 days. After the first two weeks, all manipulators will be recalibrated. The video data generated will be stereo and color, with a data rate of 3 Mbits/sec. Commercial grade components are used throughout, avoiding Mil-Spec parts when possible. Once the upper stage is grappled, the chaser will never be disconnected.

Overall, this is planned to be a high risk mission in which the robotic core vehicle is designed so that should a failure occur, it could recover. This is done by avoiding critical single-string failures and making use of the extensive experience in the neutral buoyancy facility.

#### John O'Donnell-Oceaneering Space Systems (OSS)

Mr. O'Donnell began with an overview of Oceaneering's work in space systems. Currently they support the space station project at level II.

The primary business of the company, however, is in off-shore oil exploration. Oceaneering was started in 1965 and presently has 45 offices with headquarters in Houston, TX. The aerospace portion of their business began six years ago and was the result of their recognition that many techniques that they developed for undersea operations had space applications.

Their support to NASA is primary in EVA & Robotics.

Mr. O'Donnel then described hardware which has been developed for use on the space station and which has a heritage from manipulators developed originally by GE for undersea work. This hardware has undergone development testing for space station. He also described some neutral buoyancy testing which they have done including a Satellite Servicing System (SSS) developed by TRW.

Mr. O'Donnel then described some EVA-specific systems which have been developed and tested in the neutral buoyancy facility. One such technology is the Neutral Buoyancy Portable Life Support System (NBPLSS). This was developed to eliminate the difficulties involved when performing neutral buoyancy testing in which, in the past, two additional divers were required to maneuver all of the umbilicals which supply the pressure-suited astronaut. The (NBPLSS) provides these services autonomously eliminating the need for the umbilicals. This technology has had spin-offs into hazardous material handling and fire fighting applications.

Oceaneering has also developed the tools and tool box for the Hubble servicing mission.

In their operation of the neutral buoyancy facility at MSFC, the improvements which Oceaneering has implemented have extended the underwater time in suits to over six hours.

#### Davy Haynes, NASA LaRC/STIO

Mr. Haynes presented a series of candidate missions which he had identified from the history of launch failures, and then used these missions as guidance in conducting a parametric

study addressing mission feasibility for launch performance within the range of typical SELV's.

His survey looked at five candidate missions, representing on-orbit spacecraft failures. These were: Arabsat IA (AOCS failure); Insat IC (power diode failure); Insat IA (seal failure and loss of fuel); Superbird (command error and loss of fuel); and, Palapa (Westar 6) (stranded in useless orbit).

From these candidates, Mr. Haynes defined a baseline mission for the study. For on-orbit repair, a distinction was made between restoration, replacement, and supplement. The other generic missions identified were: de-orbit and disposal; refueling; payload delivery and recovery; retrieval for repair; and, reboost.

These missions were further broken down into the types of orbits which must be reached, so as to provide a comparison for the mass-to-orbit performance of available SELV's. There are three ranges of orbits of interest. The first is Low Earth Orbit (LEO), generally altitudes up to 800 km. This will include the Hubble space telescope, Earth Observing System, the Nimbus series, and anything which was originally designed to be serviced by the Space Shuttle. The second is Medium Earth Orbit (MEO), up to 20,000 km, and reachable with a spacecraft mass of 500 to 1000 kg. The Global Positioning System (GPS) would be classified into this category. The third is Geosynchronous Orbit (GEO), specifically at an altitude of 36,000 km and an inclination of 0 degrees. This is the orbital location of most present day telecommunications satellites.

It was assumed that the basic servicer, repair, and resupply hardware would be standard 'kits' designed for general missions which could be provided on short notice when the need arises, following a 'ship and shoot' delivery philosophy. Within such a framework, the individual development time for a specific mission would be minimized.

For GEO missions, refuel or boost to a higher orbit for disposal requires only 10's of kg of propellant (within the capability of SELV's).

Reboost was evaluated assuming a 200 km circular orbit, a 290 - 300 sec specific impulse and a 2000 kg payload. It was found that with a 0.8 mass fraction, a 850 kg spacecraft can be put into GEO. This would include the spacecraft as well as the Apogee Kick Motor.

In the refueling scenario, the same spacecraft bus could be used for either a GEO or a LEO mission due to the similar requirements.

Mr. Haynes' conclusion was that the performance of available SELV's is sufficient for most LEO, some MEO and only refuel, disposal, and small and simple repair or supplementation at GEO.



## **Technology What Is Possible**

**Presentation to the Workshop On**

# **Prospects for Commercialization of SELV - Based In-Space Operations**

**October 18 & 19, 1993**

**Langley Research Center, Hampton, Virginia**

**Bill Hohwiesner  
Program Director  
Fairchild Space**

FAIRCHILD SPACE • 20301 CENTURY BOULEVARD • GERMANTOWN, MARYLAND 20874

## **Fairchild Space Satellite Servicing Background**

### **Servicing Tools Developed**

### **Maturity Of Systems & Technology To Support Automated Servicing**

### **Candidate System and Mission**



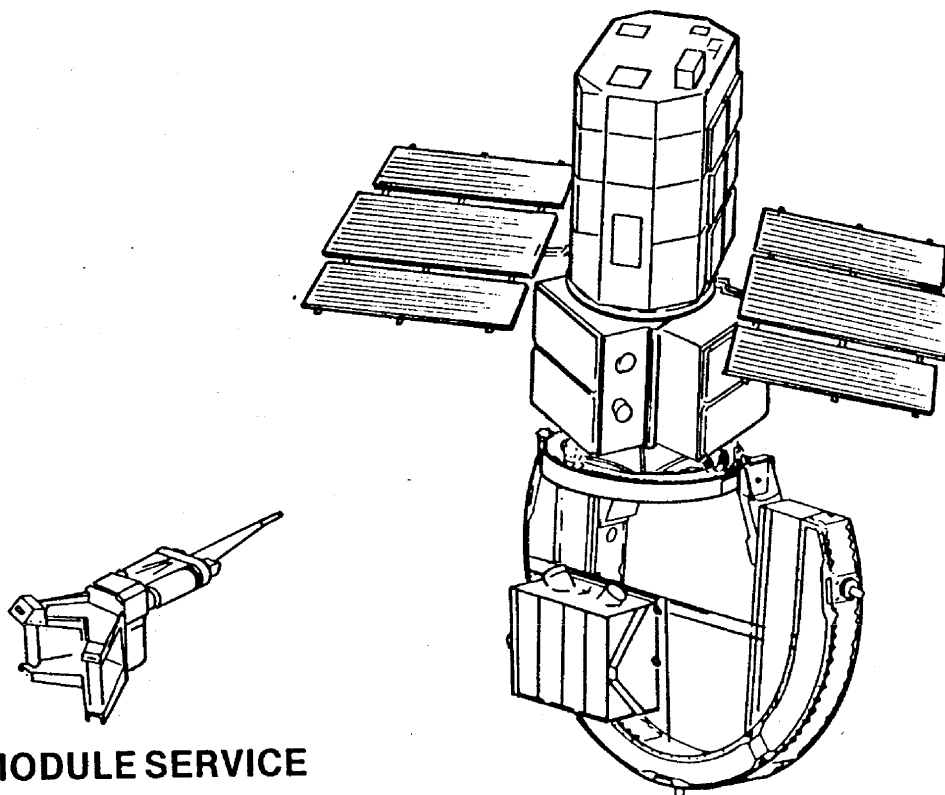
**Relation to Satellite Salvage**

- **Experience Designing & Building Hardware That Could Be Replaced On-Orbit**
- **Experience Planning and Performing On-Orbit Satellite Servicing**
- **Experience Designing the Tools for Both Manned & Unmanned Satellite Servicing**

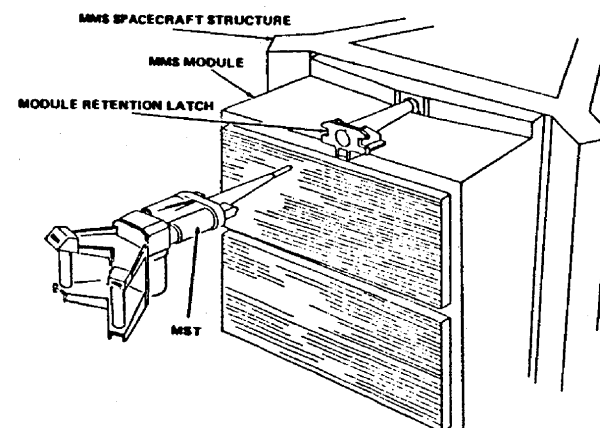
## Hardware Design for On-Orbit Replacement / Repair

- **Solar Max Satellite (launched Feb 1980)**
  - Designed and Built to be On-Orbit Serviceable and STS Recoverable
  - All Major Subsystem Modules Designed for Easy On-Orbit Removal
- **Solar Max Repair Mission (Spring 1984)**
  - First On-Orbit Servicing of a Spacecraft
  - FS Supported GSFC to Plan & Execute Mission
    - NASA I&T Contractor Responsible for  
Astronaut Tool Development  
Mission Unique Hardware  
Mission Simulation & Test
    - Designed / Modified STS Flight Support System (FSS) Hardware to Hold / Restrain  
the Spacecraft, Astronauts, and Equipment
    - Developed Module Service Tool (MST)
  - Demonstrated Capability to Service an Element Not Designed for On-Orbit Servicing  
Instrument Main Electronics Box
  - Demonstrated the Need to Go Further in Designing for Servicing / Repair

## Module Service Tool Employment on Solar Max



**MODULE SERVICE  
TOOL**



## Explorer Platform / EUVE Development

- **EP/EUVE Designed to Be More Serviceable Than SM & HST**

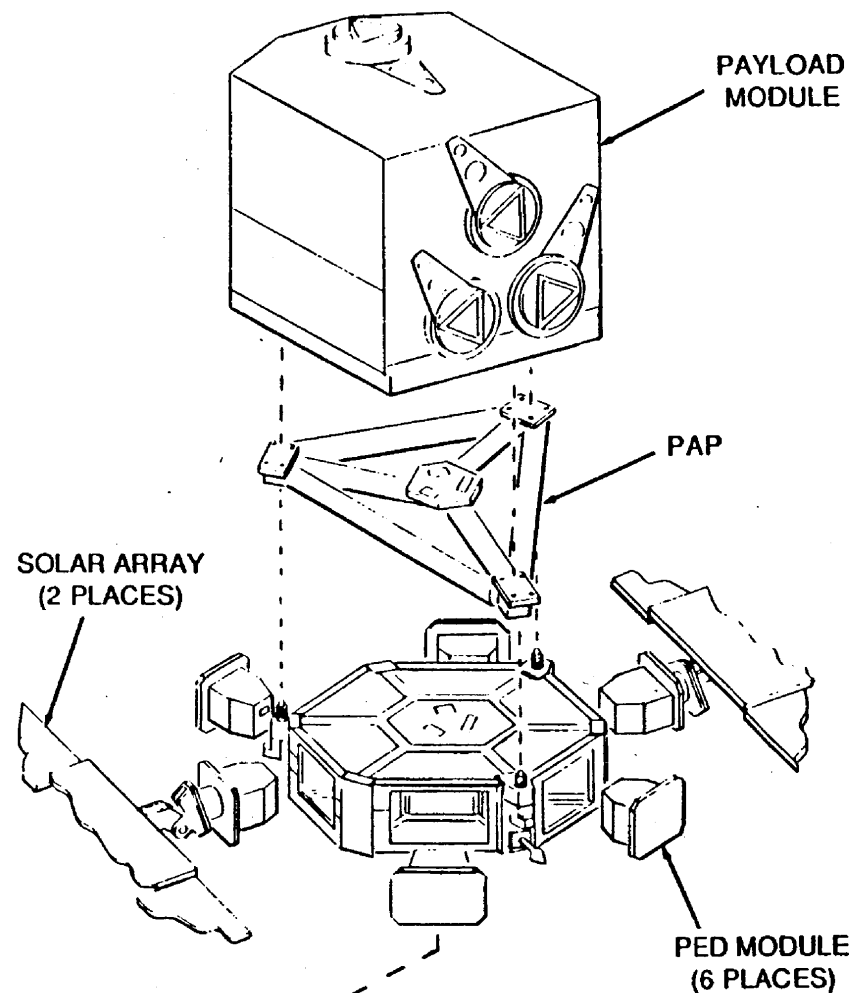
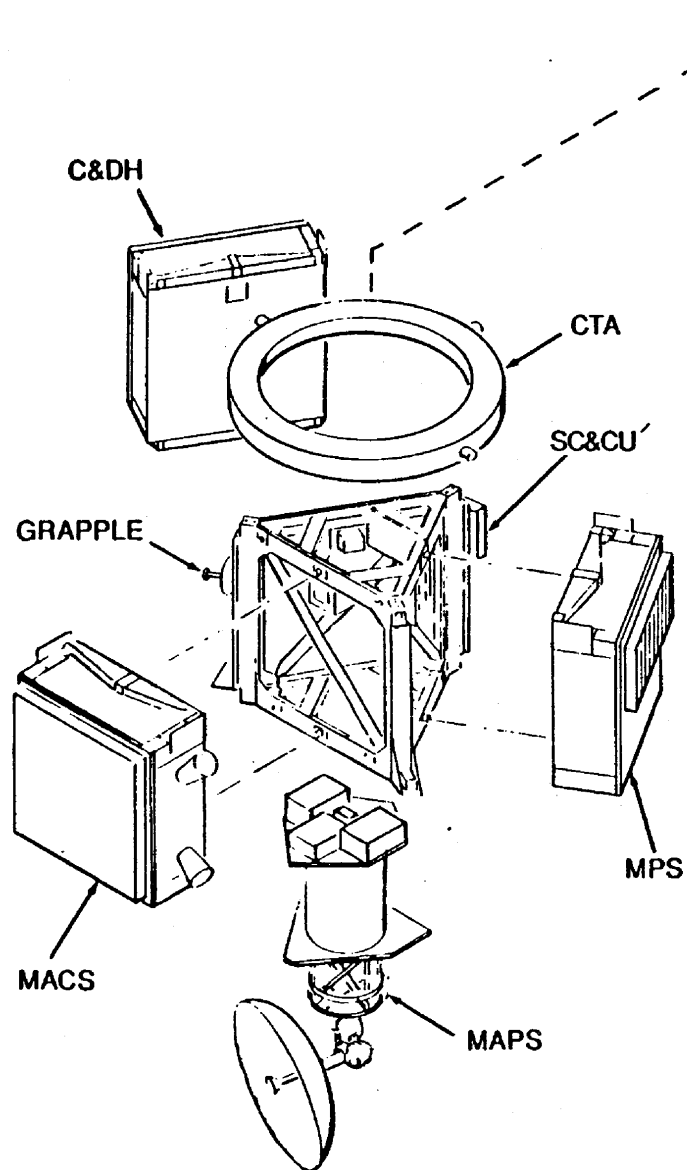
- **Designed So That Every Module Could Be Removed & Replaced Without Astronaut EVA**
  - **Employs the Servicing Aid Tool (SAT) From STS Aft Station Together With Module Service Tool to Remove & Replace Modules**
  - **SAT Can Be Controlled**
    - By an Astronaut
    - By Teleoperation from the Ground
    - Completely By Computer

Exp View

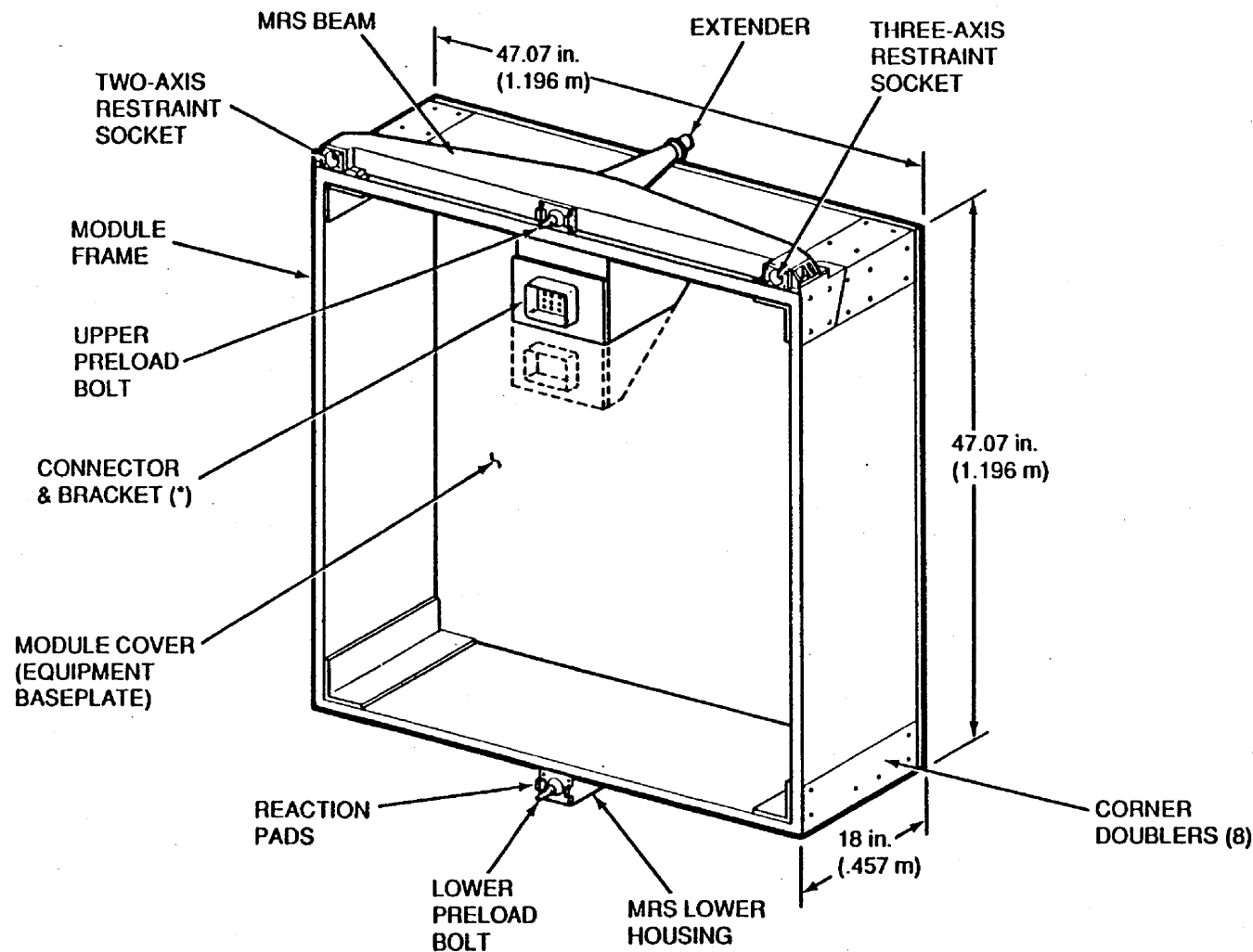
- **Key Features of EP Interfaces**

- **Modules Attached by Acme Jackscrews**
  - **Payload Module - 3**
  - **Main Modules - 2**
  - **PED Modules - 2**
- **Floting Attachment Nuts**
- **Alignment Pins**
- **Blind-Mate Electrical Connectors**
- **Grapple on Both S/C Bus and Payload Module**
- **Additional Handrails, Protective Covers, and Targets Added**

## EP / EUVE Modularity for On-Orbit Operations



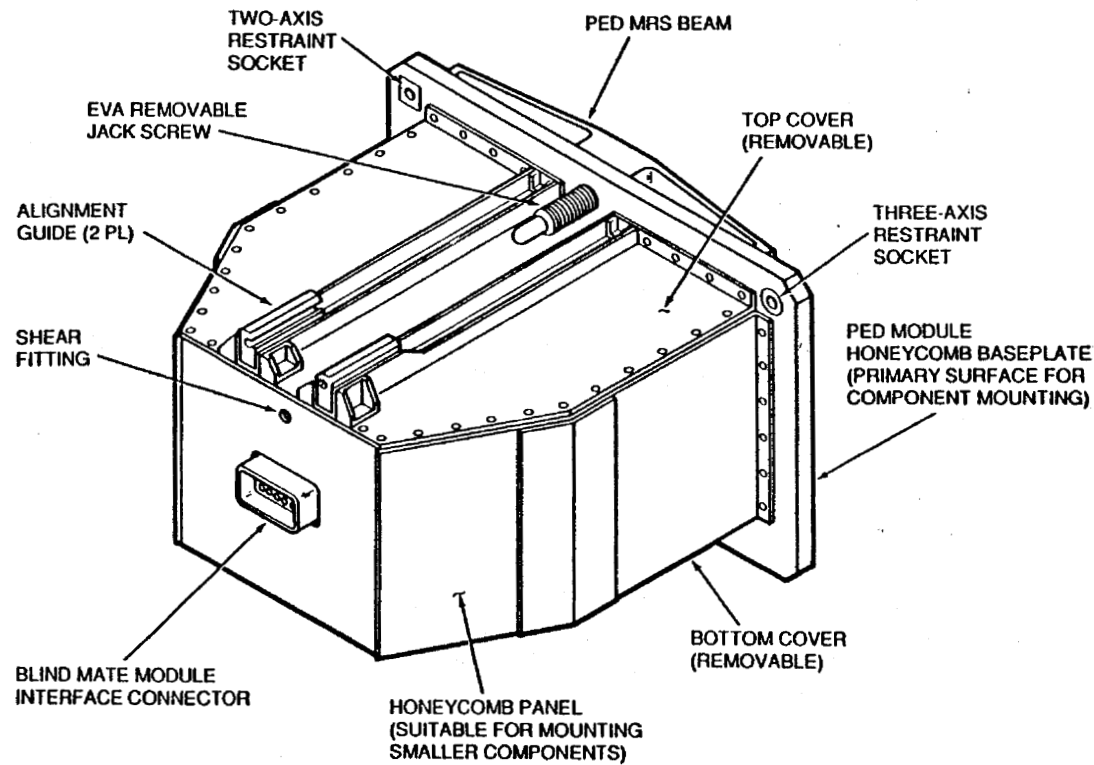
## Standard MMS Subsystem Module Structure



## EP / EUVE I/F FEATURES

Fairchild Space

### Standard Platform Equipment deck (PED) Module



## HST Servicing Support to GSFC

- **FS Responsible for Configuring and Building The Space Support Equipment for the HST Servicing Mission**
  - FSS
  - ORU Carrier
  - SA Carrier
  
- **FS Supporting HST Flight Systems and Servicing Project and Lockheed for**
  - Planning
  - Systems Engineering
  - Integration
  - Mission Operations



## **Servicing Tools for On-Orbit Replacement / Repair**

- **Module Service Tool**
  - Built for EP/EUVE Main Module Removal & Replacement
  - Used To Replace Solar Max S/C ACS Module
  - Miniaturized ( x 1/3 ) for Use With Martin Ground Evaluation
- **Servicing Aid Tool**
  - Teleoperated, Force-Reflecting, 6 DOF, 12 Ft Slave Arm
  - Designed to Support STS On-Orbit Servicing of Spacecraft
    - To Be Mounted In Cargo Bay & Is Relocatable by RMS
    - Operated From Aft Deck Using a 6 DOF Force-Reflecting Master Arm
  - Fully Computer Controllable for Autonomous Operation
  - Repeatable Positioning to Within 0.001 in
  - Designed For Up To 500 Lb Payload
  - Current Mass at About 350 Lbs (expect ELV flight unit at 150 lbs)
  - Presently Completing Flight Qualification ( TBC Jan 1994 )
  - Planned For Use On 2nd HST Servicing Mission

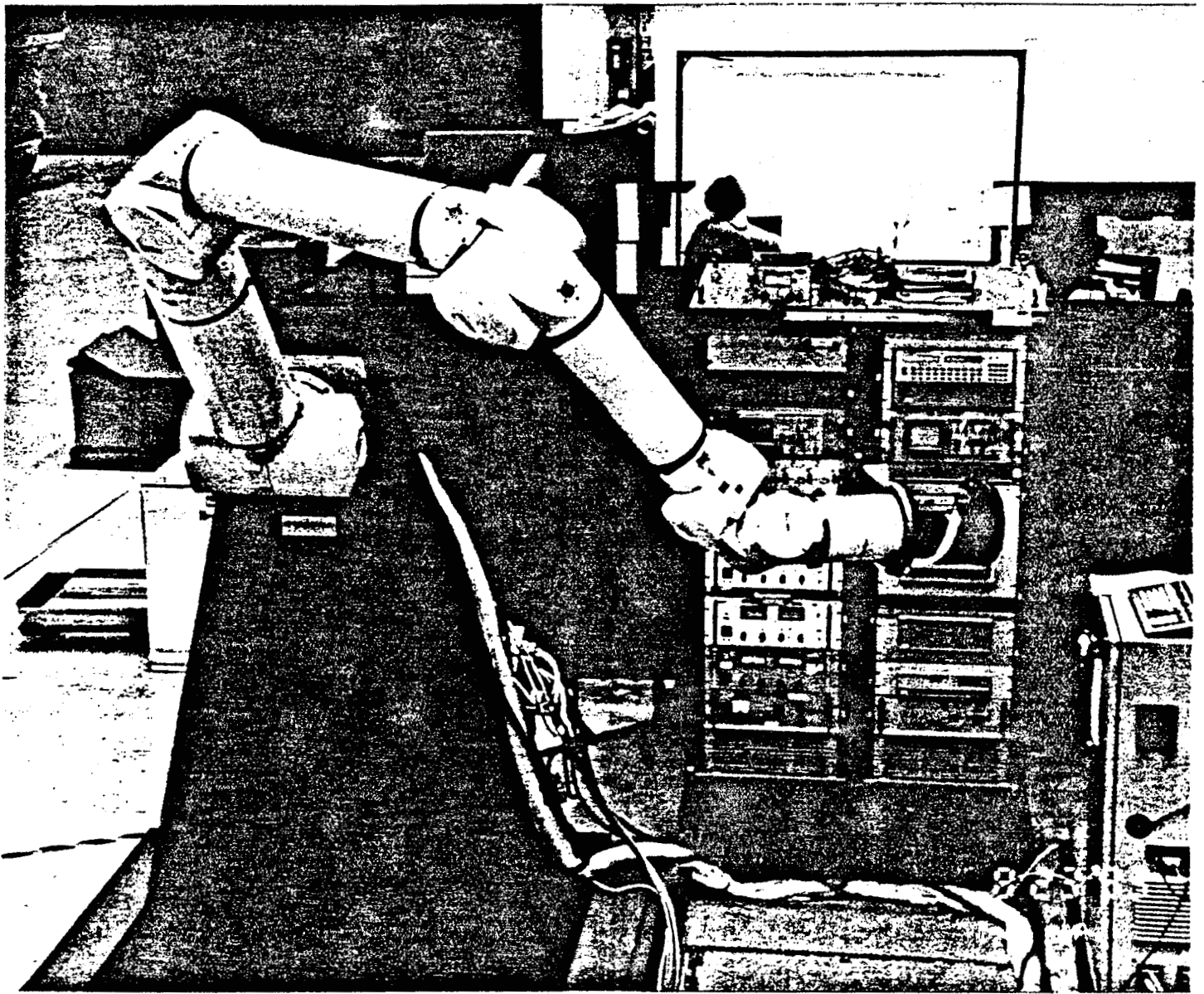
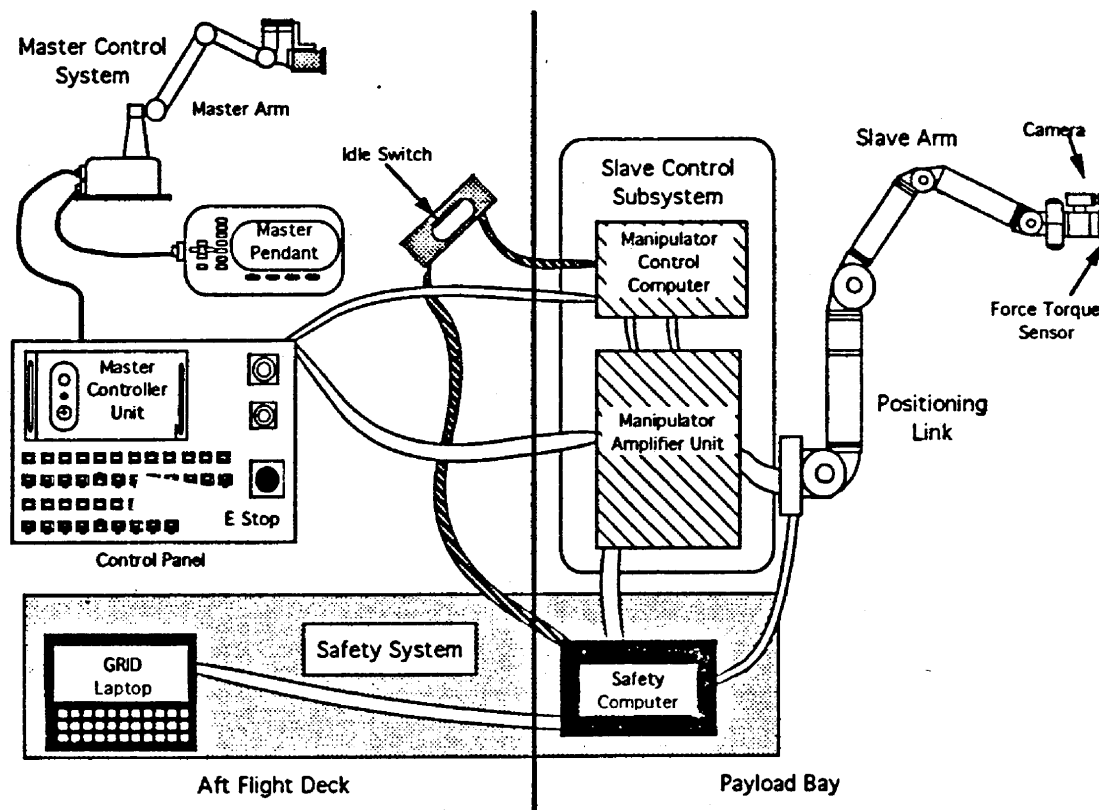


Figure 2. SAT Slave Arm With Positioner Link  
Undergoing Functional Testing

## SERVICING AID TOOL (SAT ) FEATURES

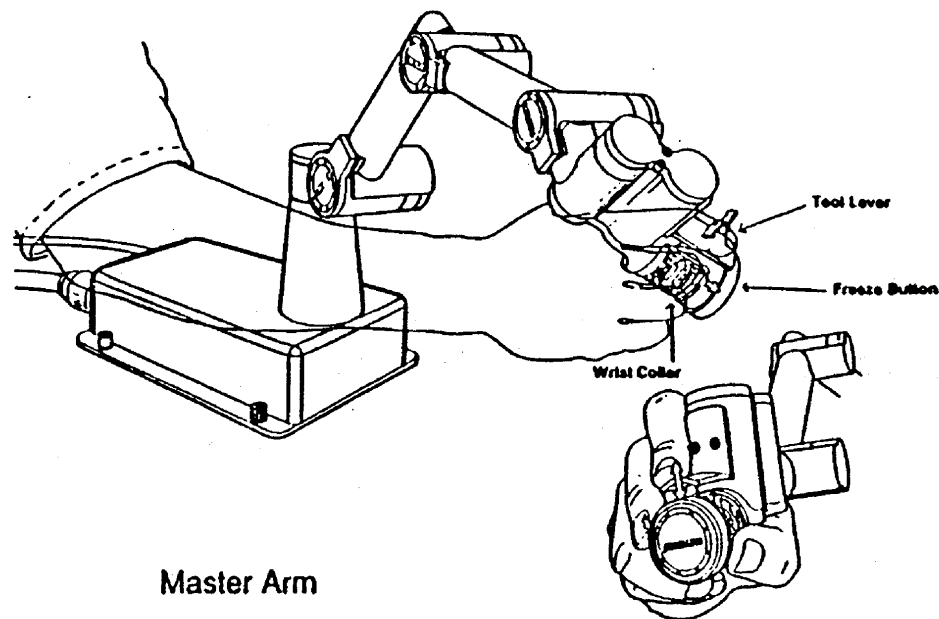
Fairchild Space

**The SAT is a Cost-Effective Servicing Tool  
Adapted From Existing Hardware For Space**



- **Master Arm**
  - Schilling Minimaster - Miniature Hand Controller
  - Kinematically Similar Master & Slave Provides Spatial Correspondence
  - Simple & Proven Joint - Joint Control System With Force Reflection
- **Slave Arm**
  - Based On Robotics Research K-Series Dexterous Manipulators
  - Employs Joint-Mounted, Torque-Controlled, Harmonic Drive Electric Motor Actuators
  - Torque-Loop Servocontrol System
  - Provides Precise Force Control At Tool
- **MCC Interface Is RS 422**

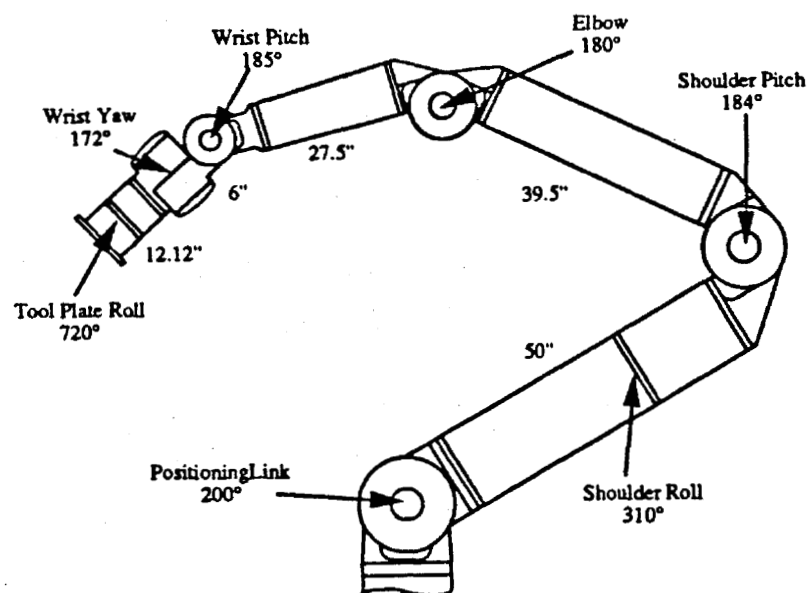
## Master Arm Controller



## SERVICING AID TOOL (SAT ) FEATURES

Fairchild Space

### Slave Arm Description



- Modular Joint Design Permits Any Combination of Joint Assemblies Or Lengths of Extension Tubes
- Reach To 135 in
- Positioning Repeatability Measured at .005 in  
- Multi-Turn Resolvers Increase This To .0005 in
- Payload Capability at 500 lbs
- Currently In Environmental Test at GSFC

### **Satellite Servicing Observations**

- **Increased Costs of Designing S/C for Serviceability Are In Added Mass and In Additional Engineering**  
**Costs Are Considerably Less Than Building Second S/C**
- **Servicing & Repair Have Demonstrated They Can Be A Cost-Effective Means To Extend S/C Life - SM & HST**
- **Servicing & Repair Enhanced When S/C Designed For Servicing Not A Requirement, However - SM MEB**
- **High Cost Of To-Date Servicing Driven By STS & EVA Costs**
- **All Servicing Accomplished To Date Can Now Be Done With Teleoperated or Automated Systems**
- **ELV-Based Servicing Now Has The Potential To Offer The Low-Cost S/C Life Extension That Had Been Originally Expected From STS**

## TECHNOLOGY READINESS TO SUPPORT AUTOMATED SERVICING

*Fairchild Space*

### The Technology Is Ready

**All Systems Required To Support Servicing & Repair Exist and Are  
Either Qualified or Are Undergoing Final Development & Qualification**

- **Structure, Power, ACS, Comm, & Propulsion Are Well Developed**
- **Video - Multiple Low Cost CCD Camera Systems Are Space Qualified**
- **GPS Receivers - Multiple Receivers Have Flown & Are Space Qualified**
- **GPS Relative Navigation - Flight Demonstration of Navigation  
Algorithms And Receiver Performance Planned For STS 69 & STS 70**
  - STS 69 Jan 1995 Use Identical GPS Receivers**
  - STS 70 May 1995 Use Dissimilar GPS Receivers**

- **Terminal / Proximity Sensors - Laser Illuminator / CCD Camera-Based Engineering Demonstration Model Working At MSFC  
Provides 5 Positional Measurements per Second  
Flight Quality Hardware Planned For 1995**
- **Terminal Navigation - Algorithms Developed And Are Operational On MSFC Flat Floor Simulation Facility  
Demonstrated Closure and Capture With 3 Point Docking System**
- **3 Point Docking System Capture Latches**
  - **3rd Generation of MSFC Latches in Final Development**
  - **Flight Quality Latching Mechanisms**
- **Automated Servicing Arm**
  - **FS Servicing Aid Tool Currently In Flight Qualification**
  - **Flight Qualification to Be Complete In Early 1994**
  - **Operates Telerobotically or Under Computer Control**



## CLASSES OF SERVICE / REPAIR MISSIONS

Fairchild Space

### Mission Characterization

#### Small Booster

- LEO, Cooperative Target
- Low Data Rate Rqmt (18 kbps)
- Video at 1 Frame per Min
- Low  $\Delta V$  Rqmt  
100-500 fps

- Perform Orbit Adjust
- Supplement Existing Subsystems  
RWA  
RCS  
ACS
- Add Small Payload

#### Medium Booster

- LEO Target non-cooperative
- High Data Rate Real-Time Video
- Teleoperation Capable
- Moderate  $\Delta V$  Rqmt

500-1500 fps

- R&R System / Payload
- Repair Subsystem
- Significant LEO Orbit Adjust
- Ignite AKM

#### Large Booster

- LEO Target non-cooperative
- High Data Rate Real-Time Video
- Teleoperation Capable
- Large  $\Delta V$  Rqmt

> 1500

- Add AKM

**Rendezvous & Docking With LEO EUVE For PED Payload Changeout**

**Rendezvous & Capture With TBD LEO S/C For Minor Repair**

## RENDEZVOUS & DOCKING WITH EUVE

Fairchild Space

- **Mission Objective**
  - Demonstrate Automated Rendezvous & Docking With Cooperative S/C**
  - Demonstrate Automated PED Changeout To Add New Payload**
  - Investigate Teleoperation Capabilities of SAT With Limited Video**
- **Mission Overview**
  - Configure Small Satellite Chaser For Pegasus Launch by Fall 1995**
  - Assumptions**
    - 3 Day Mission Against A Cooperative Target**
    - TDRSS SMA**
    - Multiple Hold Points For Ground Monitor**
    - Single String Reliability**
  - Day 0          Pegasus Launch & Chaser Checkout**
  - Day 0.5        Begin Rendezvous Ops Using GPS & Relative Navigation**
  - Day 1.0        Arrive At Hold Point 500 m In Trail With EUVE**
  - Day 1-3        Conduct Docking, P/L Changeout & Prox Ops**  
**Navigation Via Rel Nav & Laser Ranging & Positioning System**

## EUVE Capabilities

The EP was launched June 7, 1992 with the Extreme Ultraviolet Explorer payload to 528 Km circular at 28°.

### MASS

- EP Spacecraft Bus and EUVE 3267 kg

### POWER

- Total Power BOL :1025 Average W, 3000 W Peak
- Available for Payload 470 W avg., 1000W Peak
- Rotating Solar Arrays

### COMMUNICATION & DATA HANDLING

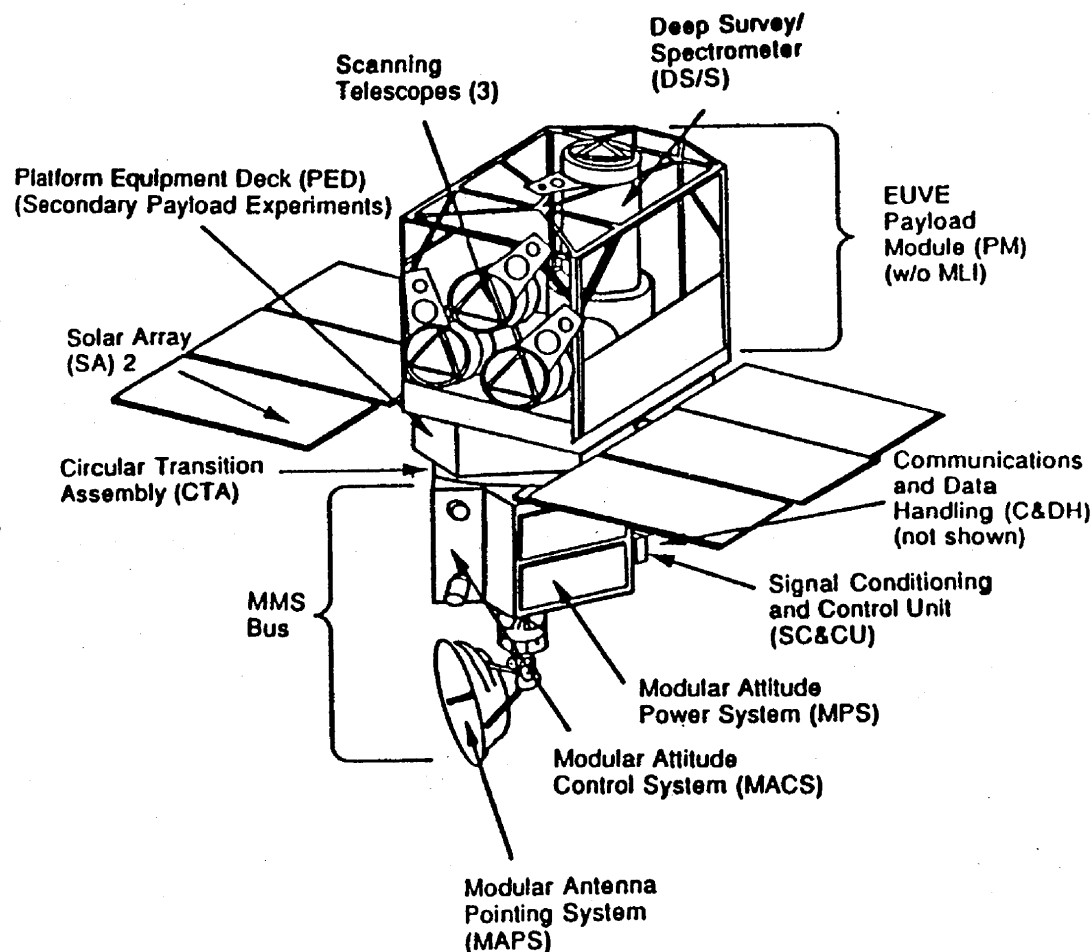
- Two 1 Gigabit Recorders
- Multiplex Databus with 1 MHz Clock
- 5 Watt Transponder
- Uplink TDRSS SMA 1 KBPS DSN Backup
- Downlink TDRSS SSA 512 KBPS / SMA 32 KBPS

### ATTITUDE CONTROL

- Zero Momentum, 3-Axis Stabilized
- Gyro Reference with Stellar Reference
- Inertia 45000 Slug-ft Max
- 4 RWAs; 60 Ft-Lb-Sec ea
- SLEW Time 90° In 7 Minutes for 5000 Slug-ft
- Knowledge to 1 Arc Second

### SPACECRAFT RELIABILITY

- Based On Historical Data - Weibul Distribution
- Prob to last 3 yrs - .883
- Prob to last 6 yrs - .785
- Prob to last 9 yrs - .711
- Prob to last year 4 through year 6 - .89
- Prob to last year 7 through year 9 - .905

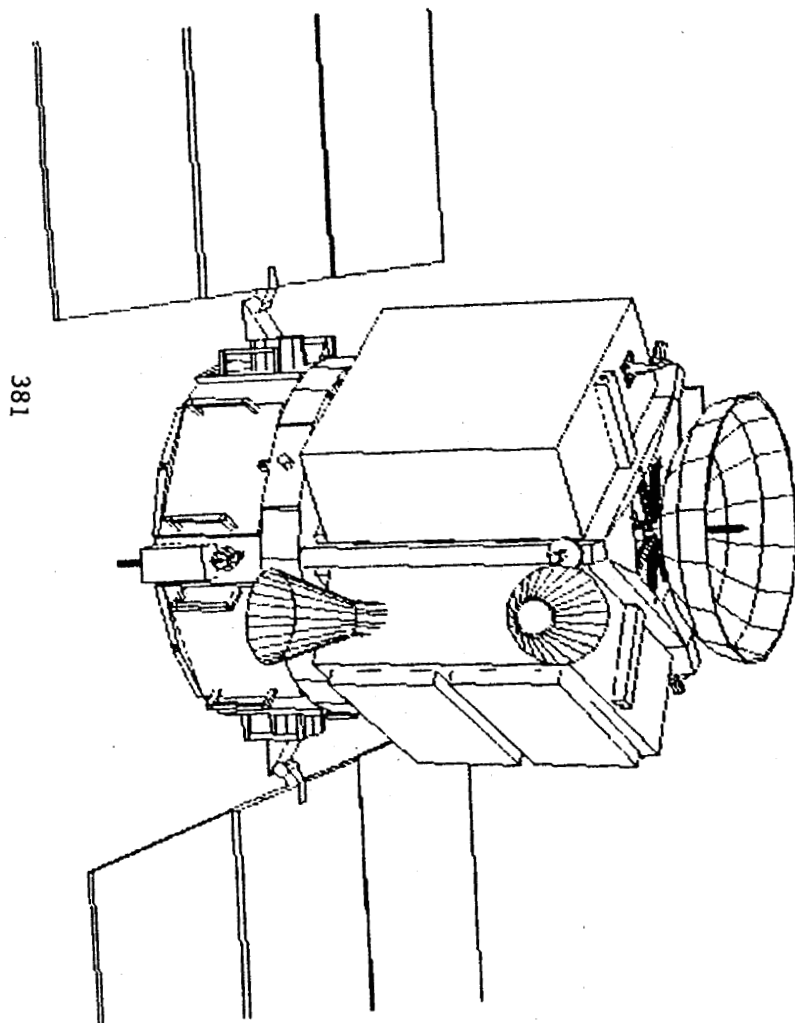


## RENDEZVOUS & DOCKING WITH EUVE

**Fairchild Space**

### EUVE Capabilities

#### Explorer Platform Provides Attractive Target Capabilities



**Explorer Platform as Target**  
Side View

#### Robust Attitude Control System

Can Fly Either Earth or Inertially/Sun  
Pointed Modes Indefinitely

Attitude Knowledge to  $< .05^\circ$

Control to  $< .5^\circ$

Stable to  $< .008^\circ$

Momentum Biased or Zero Momentum

ACS Can Control EP Prior to, During,  
And Following Docking With One  
Common Control Mode

Thermal Control System Designed to  
Accommodate Either Sun or earth  
Pointing

## EUVE Capabilities

### GPS Receiver Onboard For Precision Navigation

Motorola 12 Channel C/A & P Code Receiver

Provides Absolute GPS Position of EP

EP Provides GPSR Data In TM Stream to Enable Relative GPS Navigation

### Optical Retroreflectors On Bottom to Aid Proximity Operations

## EUVE Capabilities

### Retroreflector Mounting On Bottom Of EP

JSC BRACKET - POWER MODULE  
14" X 10" X .25"

MSFC/CNES BRACKET - C&DH  
15" X 7" X .25"

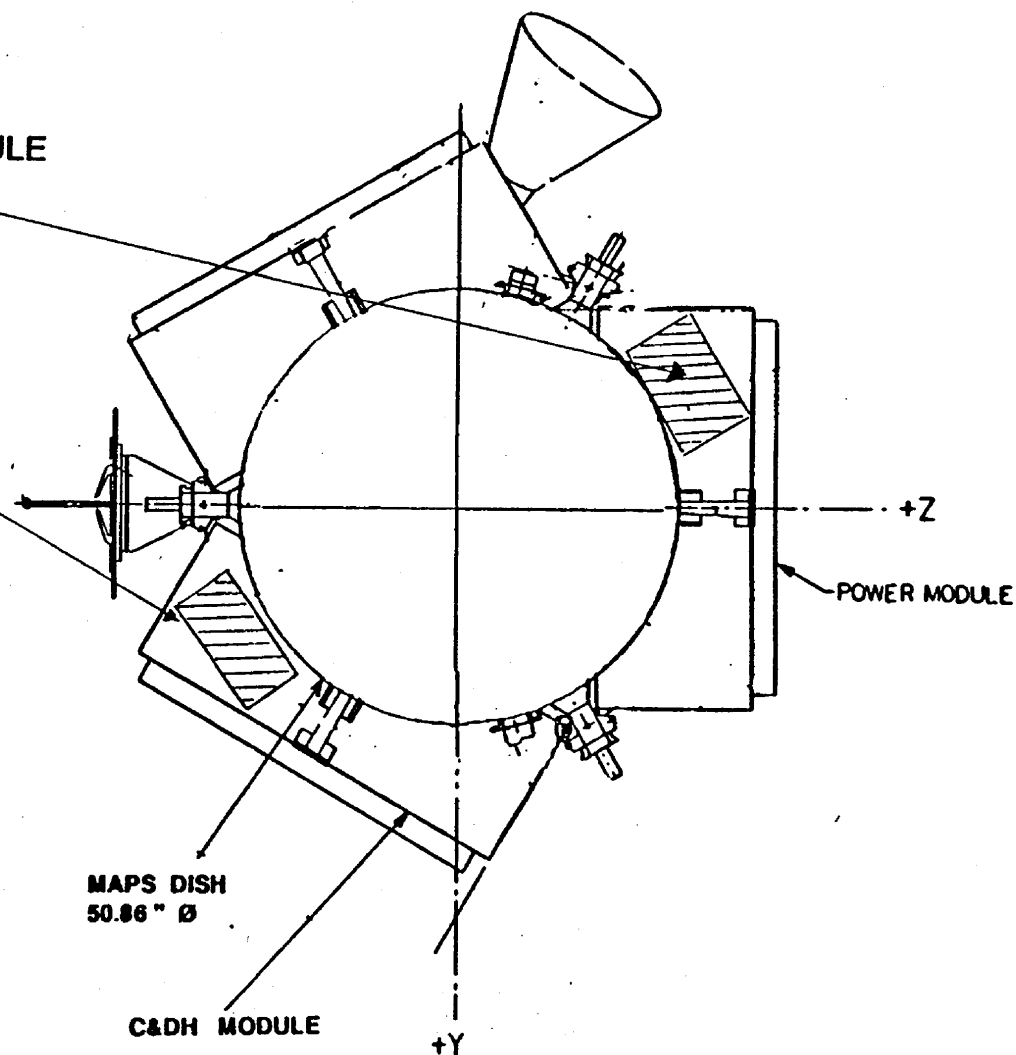
MAPS DISH  
50.86" Ø

C&DH MODULE

POWER MODULE

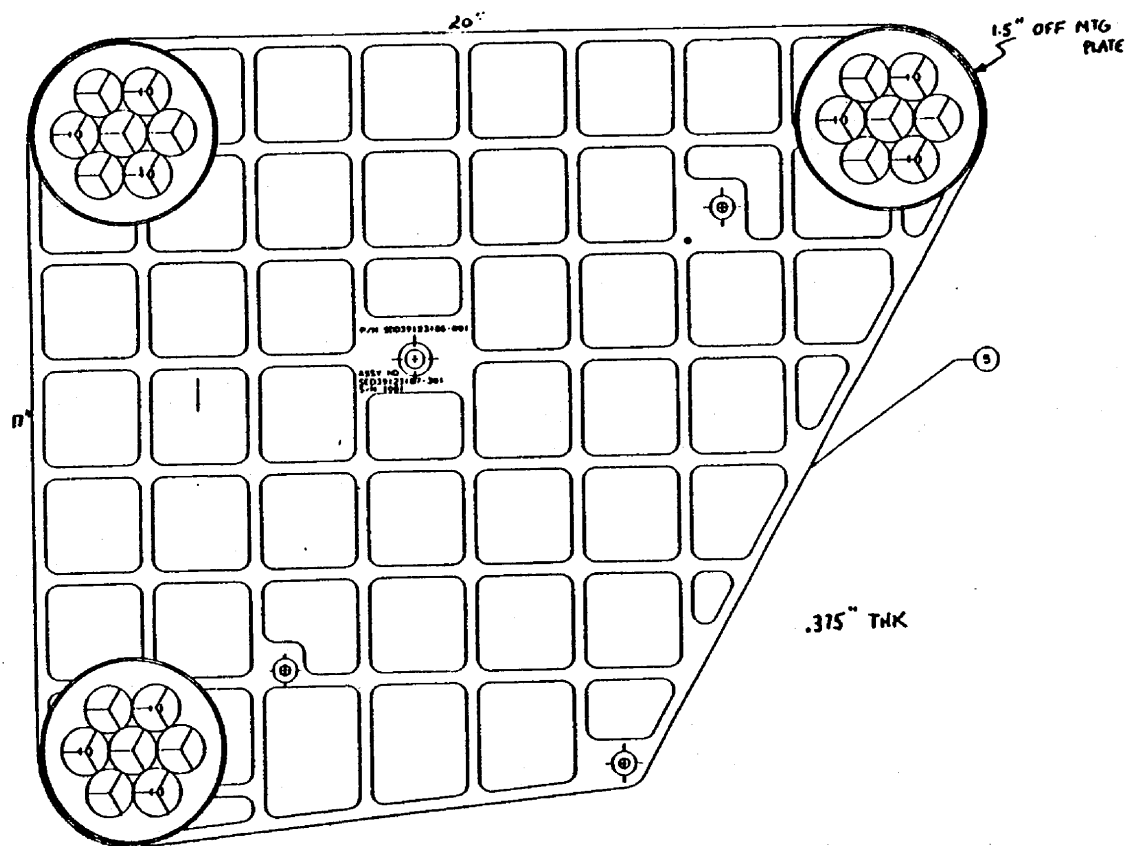
+Z

+Y



## EUVE Capabilities

### JSC Retroreflector



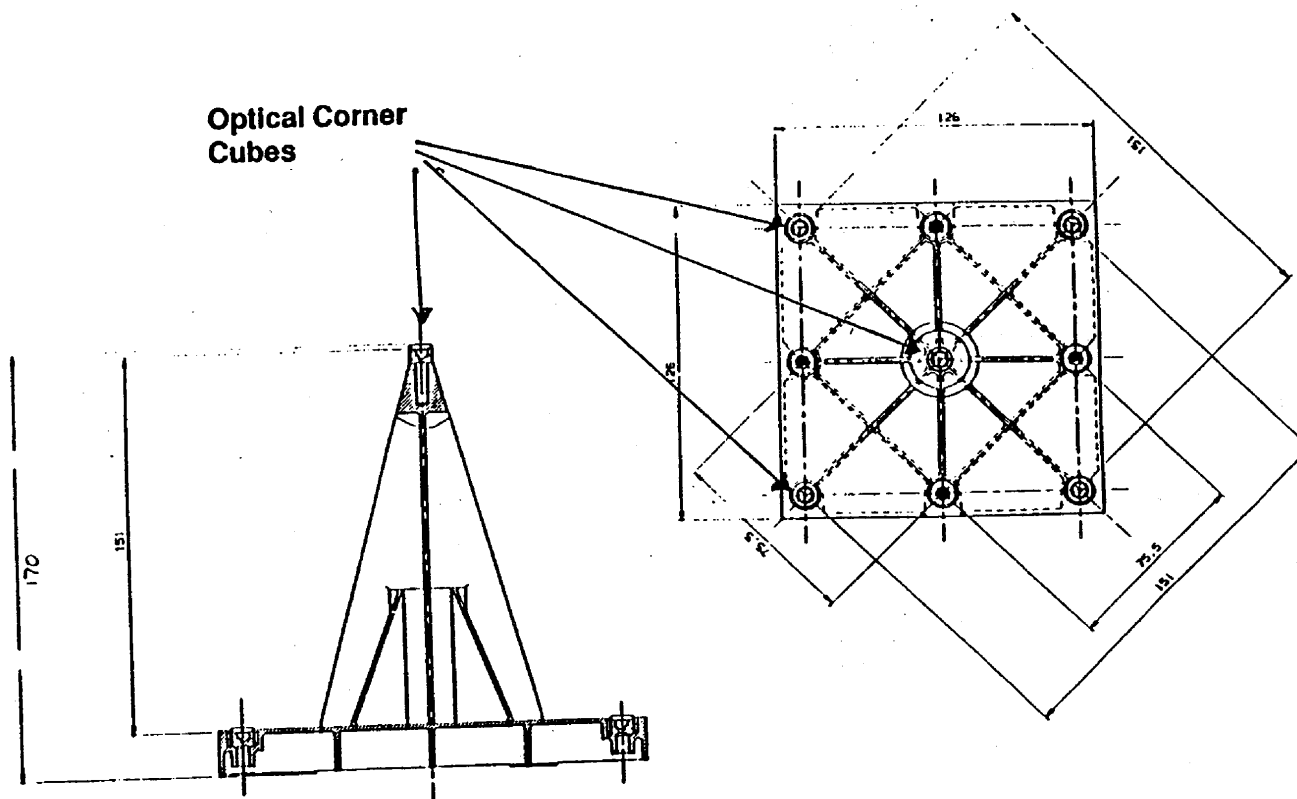


## RENDEZVOUS & DOCKING WITH EUVE

Fairchild Space

### EUVE Capabilities

### CNES Retroreflector

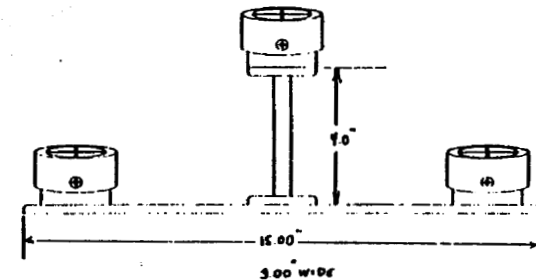


- O DIMENSIONS: 5" SQUARE BASE WITH 7" HIGH PYRAMID TOP
- O WEIGHT: 2 LBS

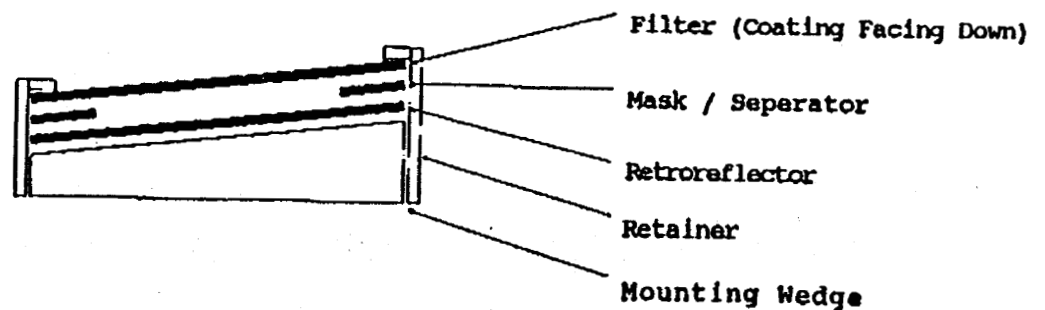
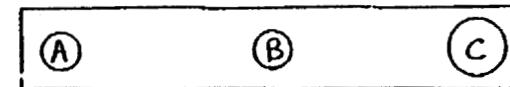
## EUVE Capabilities

### MSFC Retroreflector

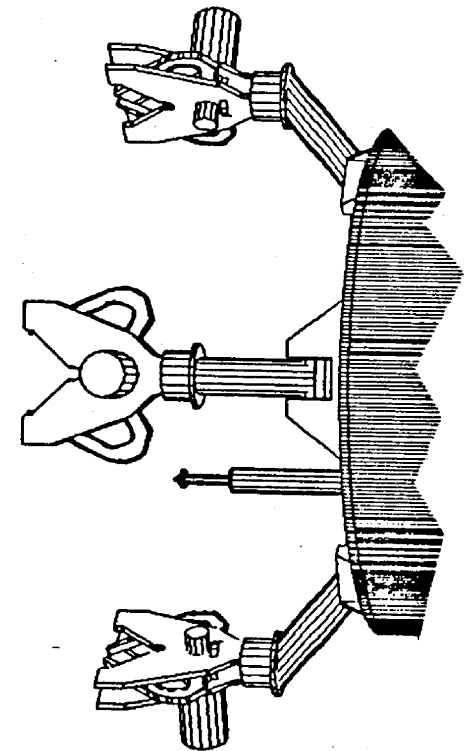
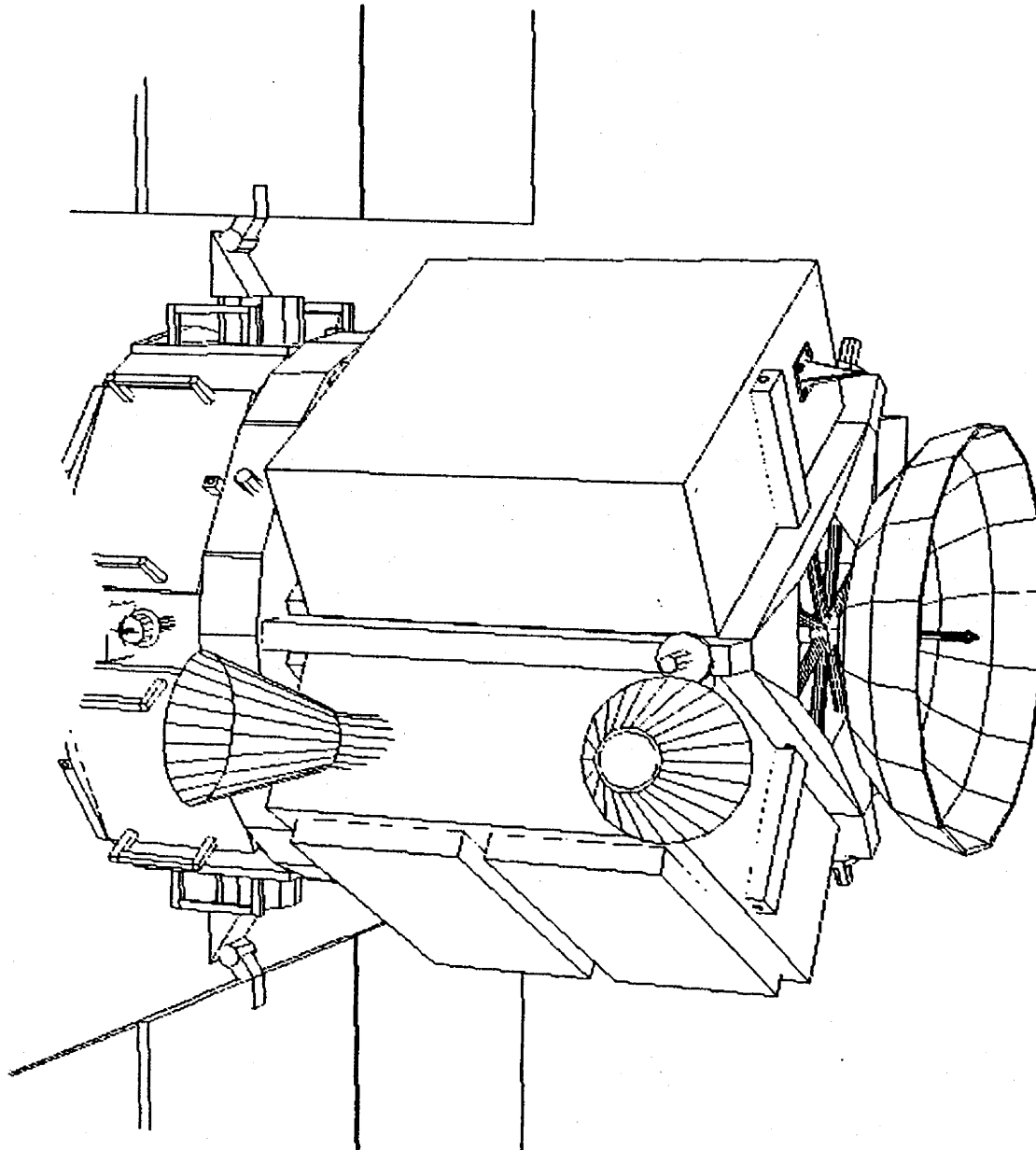
- O DIMENSIONS: 15" X 3" X .25" MOUNTING PLATE  
1" DIAMETER X 1.5" UNIT A  
1" DIAMETER X 1.5" UNIT B ON 4" POST  
1.5" DIAMETER X 1.5" UNIT C
- O WEIGHT: 3 LBS



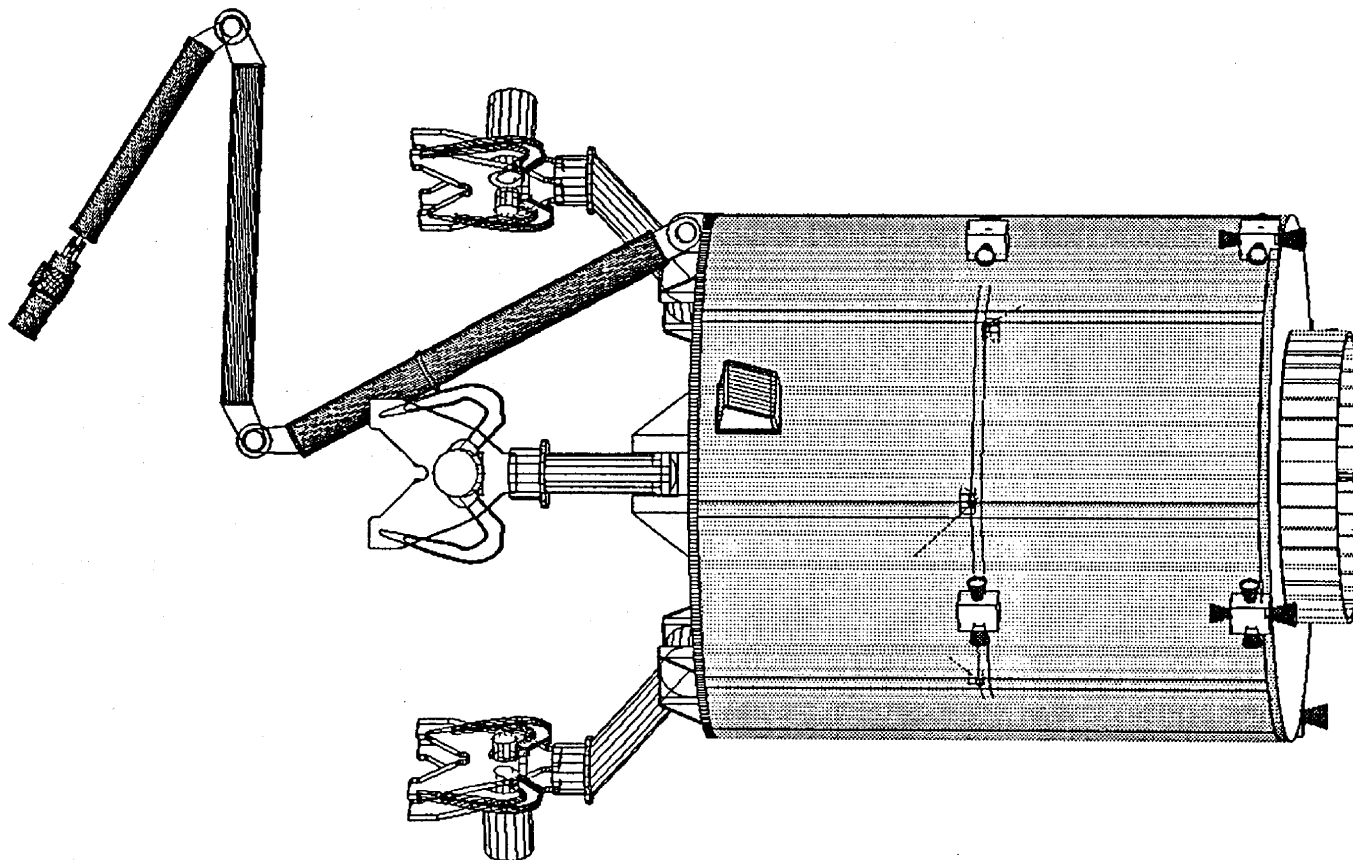
Target Configuration



## Deployed Docking Mechanism On Approach



## Chaser Configuration

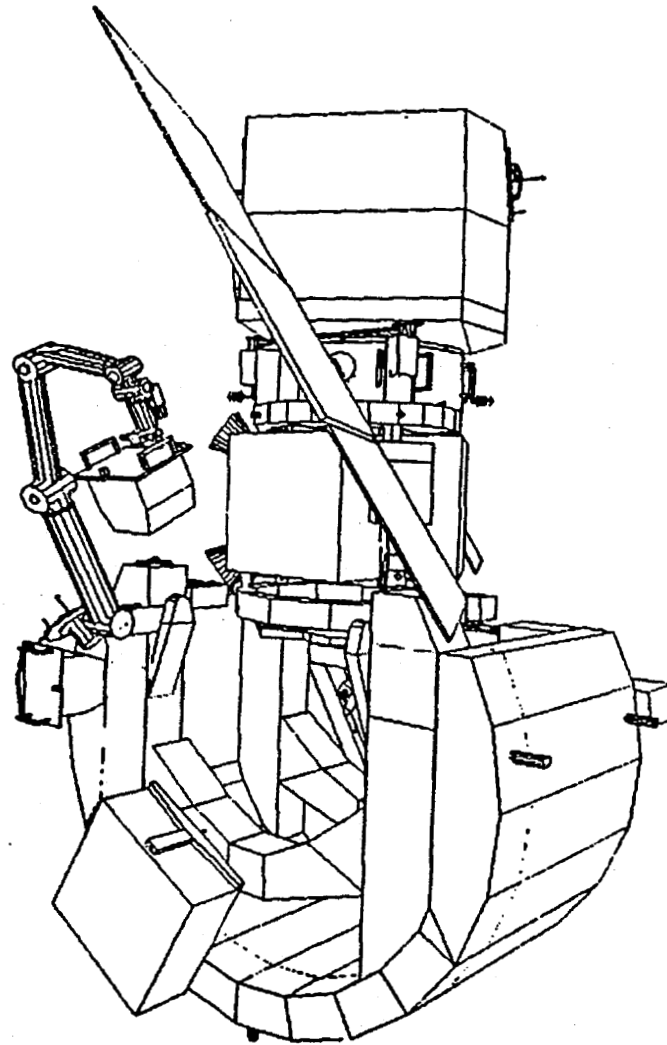


Chaser Configuration

• Structure Based On Fairchild Small Satellite Structure MSFC 3 Point Docking Latches FS SAT	335
• Power Subsystem Uses Silver Zinc Batteries With Limited Recharge	140
• ACS Uses FSS & T Scan Wheels With GPS AD As Backup	20
• Proximity Sensor & Electronics Developed By MSFC	30
• Closure & Capture Algorithms Currently Working At MSFC	
• Hydrazine Propulsion	90
• TDRSS Transponder	30
• OBC Based On	35
• PED Payload Module	50
• Margin	35

Chaser Mass 760 Lbs

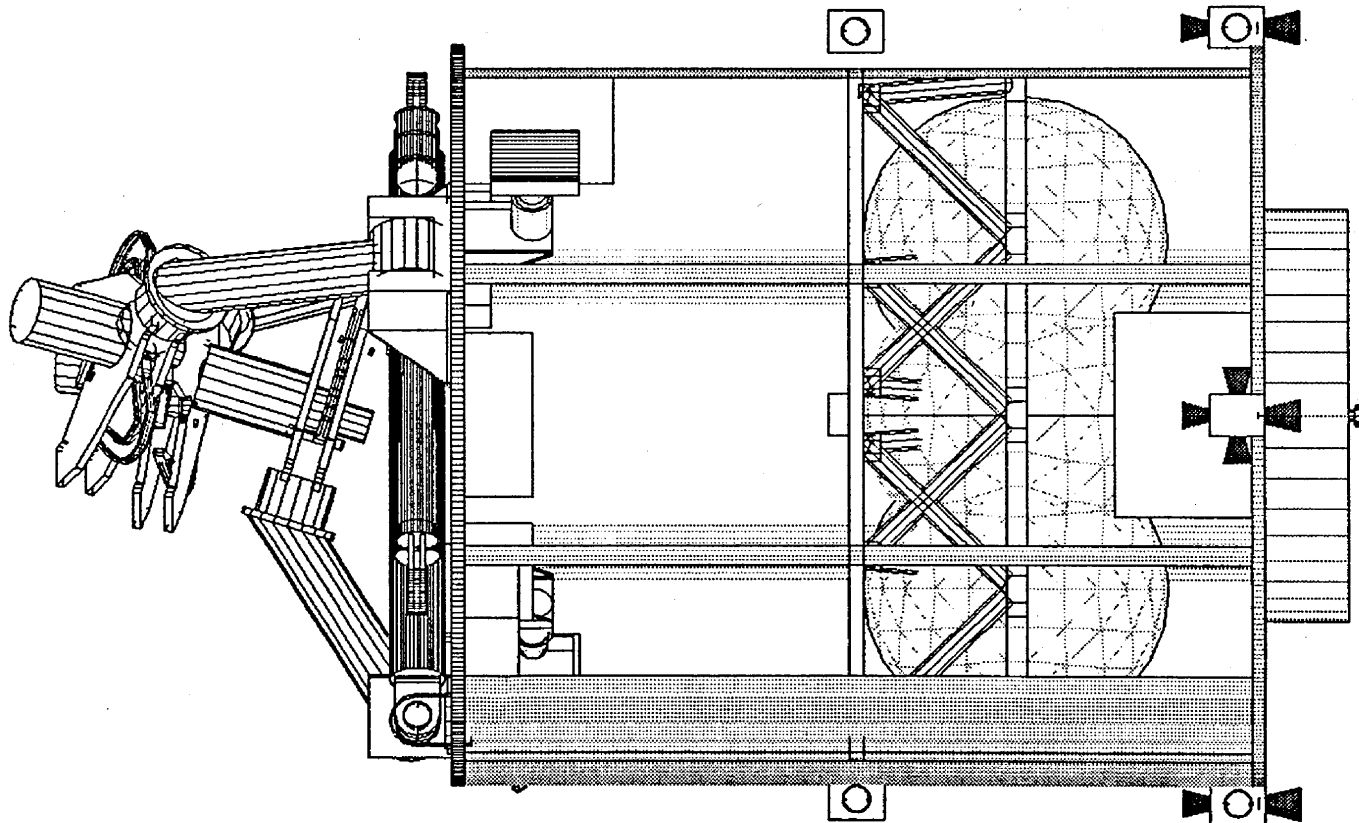
## SAT Replacing PED Module - Earlier Concept



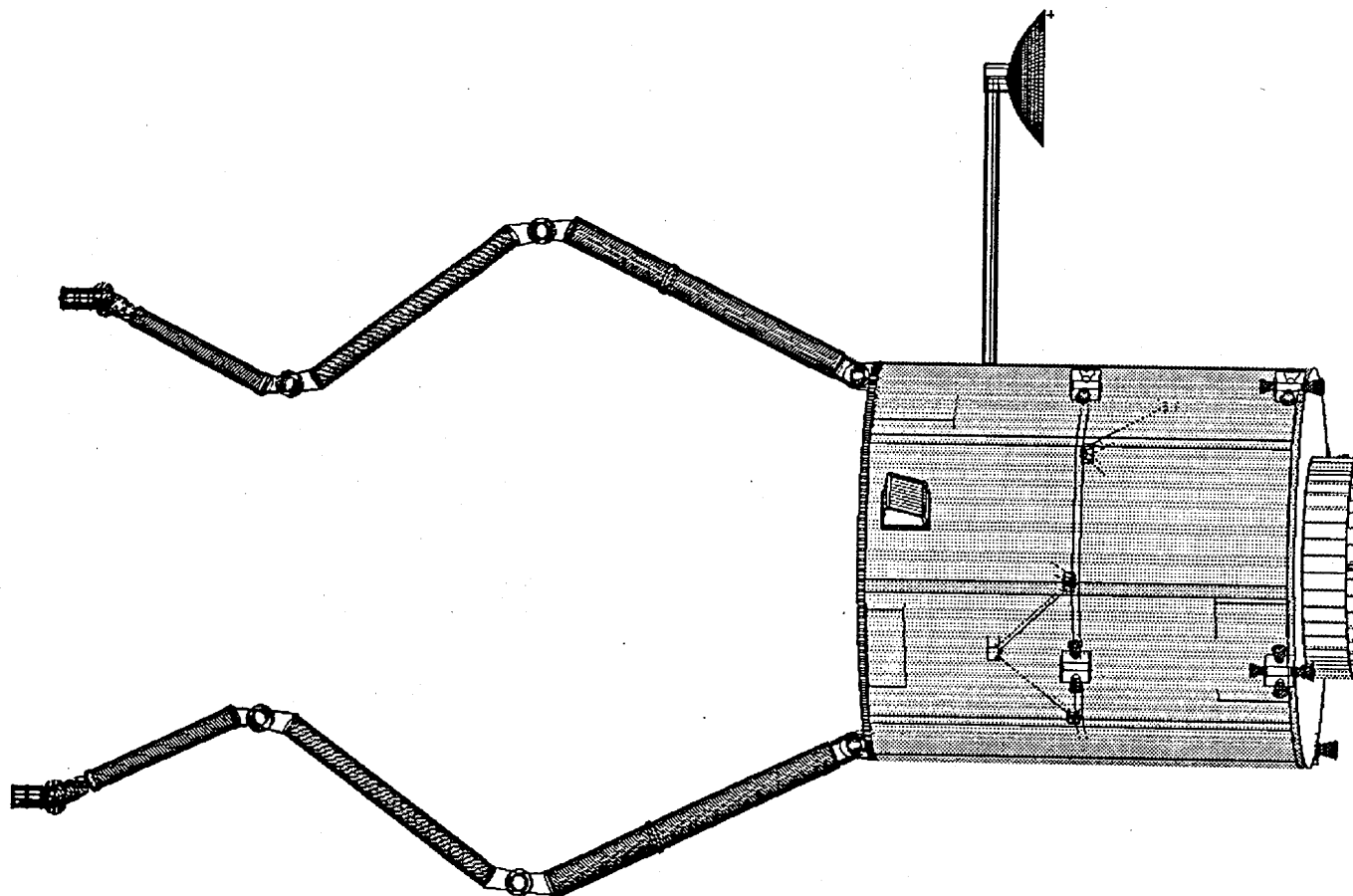
## RENDEZVOUS & DOCKING WITH EUVE

*Fairchild Space*

### Chaser Configuration



## Configuration to Accomplish Minor Repairs





**TECHNOLOGIES ARE READY TO SUPPORT  
AN ELV-BASED  
1995 SERVICING AND REPAIR MISSION**

**COSTS ARE NOW APPROACHING THE LEVEL  
THAT CAN PERMIT  
SELECTIVE SATELLITE RESCUE AND REPAIR**

# THE SERVICING AID TOOL: A TELEOPERATED ROBOTICS SYSTEM FOR SPACE APPLICATIONS

Keith W. Dorman, John L. Pullen & William O. Kekszy

*Fairchild Space*

20301 Century Blvd., Germantown, Md. 20874

James P. Karlen, Paul H. Eismann & Keith A. Kowalski

*Robotics Research Corporation*

P. O. Box 206, Amelia, Oh. 45102

## ABSTRACT

The Servicing Aid Tool (SAT) is a teleoperated, force-reflecting manipulation system designed for use on NASA's Space Shuttle. The system will assist Extravehicular Activity (EVA) servicing of spacecraft such as the Hubble Space Telescope. The SAT stands out from other robotics development programs in that special attention has been given to provide a low-cost, space-qualified design which can easily and inexpensively be re-configured and/or enhanced through the addition of existing NASA funded technology as that technology matures. SAT components are spaceflight adaptations of existing ground-based designs from Robotics Research Corporation (RRC), the leading supplier of robotics systems to the NASA and university research community in the United States. Fairchild Space is the prime contractor and provides the control electronics, safety system, system integration and qualification testing. The manipulator consists of a 6-DOF Slave Arm mounted on a 1-DOF Positioning Link in the shuttle payload bay. The Slave Arm is controlled via a highly similar, 6-DOF, force-reflecting Master Arm from Schilling Development, Inc. This work is being performed under contract to the Goddard Space Flight Center Code, Code 442, Hubble Space Telescope Flight Systems and Servicing Project.

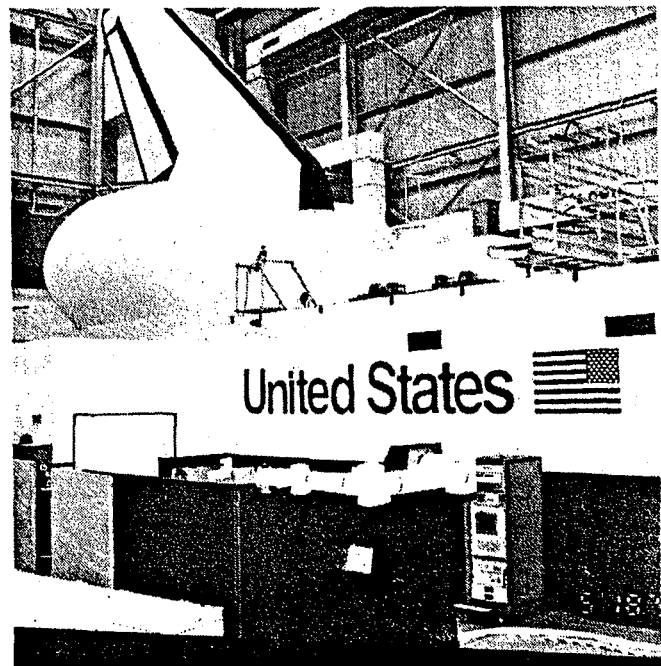


Figure 1. SAT Slave Arm at the GSFC

## INTRODUCTION

In 1989, the Goddard Space Flight Center (GSFC) released a RFP for a low-cost, flight-capable, teleoperated robot system which could support 1G testing and training, and significantly improve on-orbit servicing of spacecraft. The subject robotics development program has been based on adaptations of existing robotics and military hardware, compatibility with existing and proven GSFC avionics used on the shuttle, slave arms directly descendant from the majority of robotics technology development platforms used throughout NASA and the universities, and designed ready to incorporate additional operational and controls features as may be required.

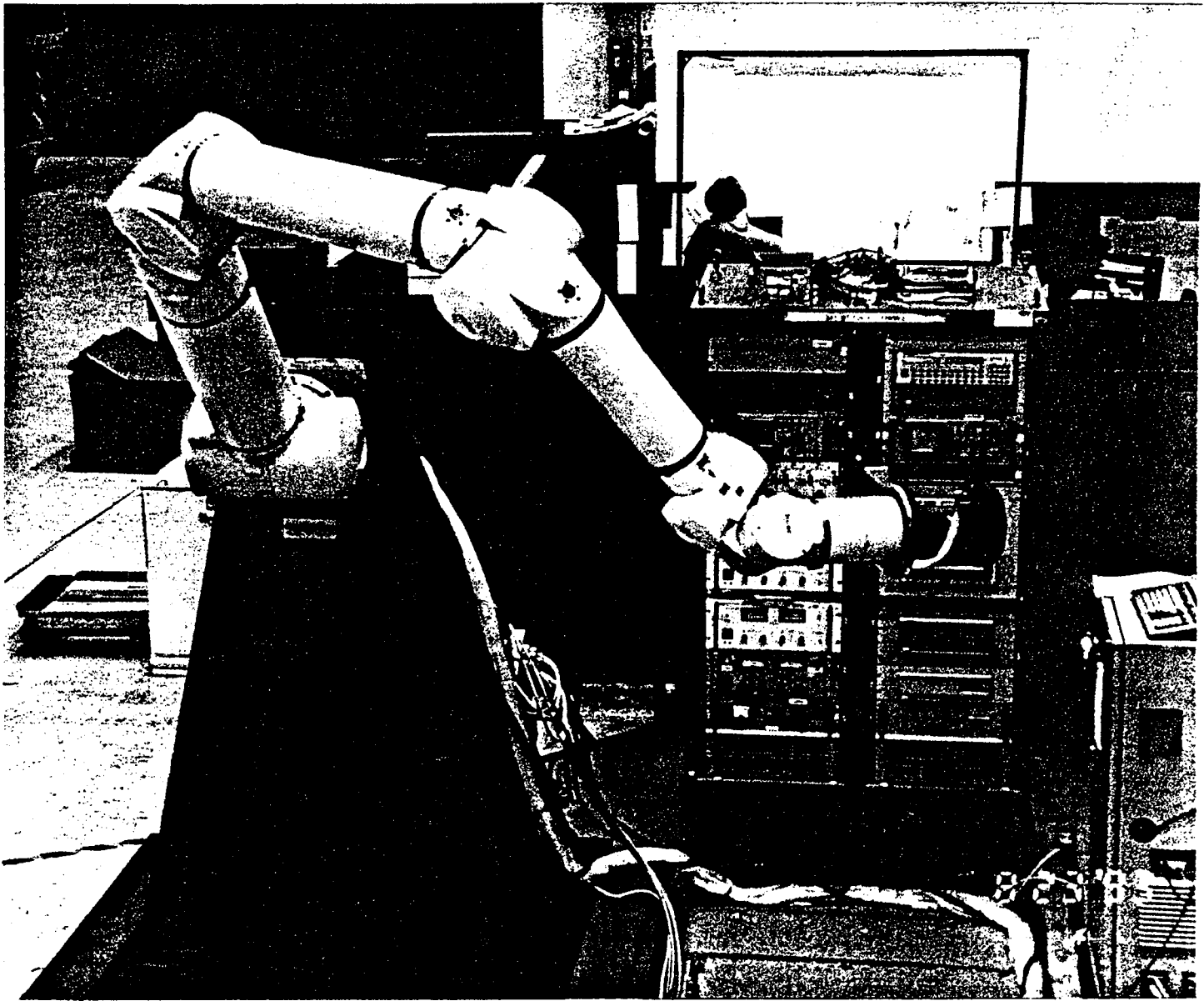


Figure 2. SAT Slave Arm With Positioner Link  
Undergoing Functional Testing

The SAT stands out from other robotics arms in the flexibility of its design to conform and adapt to changing needs with relatively little expense in doing so. Varying mission requirements and uncertain final requirements for safety compliance (anyone familiar with the safety review process knows that many failure mechanisms and corrective action requirements are not identified until the latter stages of the safety review process—not the Phase 0 or 1 levels) have received due consideration in the construction of the SAT. The SAT arm mechanism, shown in Figures 1 and 2, is composed of a series of self-contained joint drive modules joined by quick-disconnect band clamps. Thus, it would be easy to re-configure the system to suit different user needs and applications. For instance, the current SAT Slave Arm has an 85 inch reach (shoulder centroid to toolplate). If determined to be advantageous for some particular flight application, the arm could be reduced to 60 inches in reach—or 48 inches or whatever dimension was appropriate—simply by shortening the hollow tubes which make up the forearm and upper arm segments. Alternatively, an additional joint could be added into one of these hollow tubes to provide increased dexterity as discussed latter in this paper.

Furthermore, the control computer has a substantial amount of growth capacity. Of 15 slots in the multibus chassis assembly, only 8 are currently used. Less than 10% of the bus bandwidth, and only 60% of the computational capacity is currently being utilized. Likewise, the companion electronics assembly to the control computer also has plenty of spare connector ports, relays, and power distribution to provide expansion.

Since the SAT is an operational 1G system it is the ideal candidate for technology transfer. Since their introduction in 1987, seven degree-of-freedom, position/force-controlled manipulators designed and manufactured by Robotics Research Corporation have served as the standard development platform across the NASA community for work in dexterous manipulation and space tele-robotics. Users include the telerobotics laboratories at the Jet Propulsion Laboratory, Johnson Space Flight Center, Langley Research Center, Goddard Space Flight Center, the National Institute of Standards and Technology, Lockheed Engineering & Sciences Company, Lockheed Missiles & Space Company, Grumman Space & Electronics Group, Space Systems/ Loral, Fairchild Space & Defense Corporation, the University of Tennessee, Case Western Reserve University and NEC (Japan). As a consequence, a considerable body of

advanced control technology compatible with these products, as well as in-depth application and integration experience, now exists.

At least 39 separate research and development projects have been undertaken by researchers in this community to date, 29 of which were conducted at NASA and NIST since 1987 (including 10 current NASA projects) and the remainder at academic institutions and research oriented companies.

New technology developed in these projects include alternative approaches to kinematics for 7-DOF manipulators, high bandwidth force control software using the internal joint torque sensors provided in RRC arms, calibration techniques for redundant arms, evaluations of alternate hand controllers and user interfaces, and architectures for high-level autonomous and supervisory control systems. Applications demonstrated to date include Space Station inspection, Space Station truss assembly, satellite servicing tasks, on-orbit assembly of aero brakes, simulation of spacecraft docking mechanisms and the development of robot-friendly truss fasteners.

Recently, several large U. S. industrial corporations have begun seriously evaluating the use of RRC type manipulators for factory use. In this light, the SAT offers an excellent vehicle by which to implement NASA-funded technology toward improved national competitiveness.

---

## SYSTEM DESCRIPTION

The Servicing Aid Tool (SAT) is designed to allow an Operator to control a teleoperated six degree of freedom Slave Arm using a six degree of freedom, force-reflecting Master Arm. The master and slave arms have highly similar kinematic arrangements, both being configured in the same manner: a roll/pitch shoulder, a pitch elbow, and a pitch/yaw/roll wrist.

This allows use of a joint-to-joint control scheme: a joint on the Slave Arm is commanded by motion of only the corresponding Master Arm joint, and a torque signal is provided to each Master Arm joint as a result of the state of the corresponding Slave joint. Force commands are reflected to each master joint based on the corresponding slave joint torque sensor. The torque sensor also provides feedback for a local analog torque loop which eliminates the effect of friction in the joint.

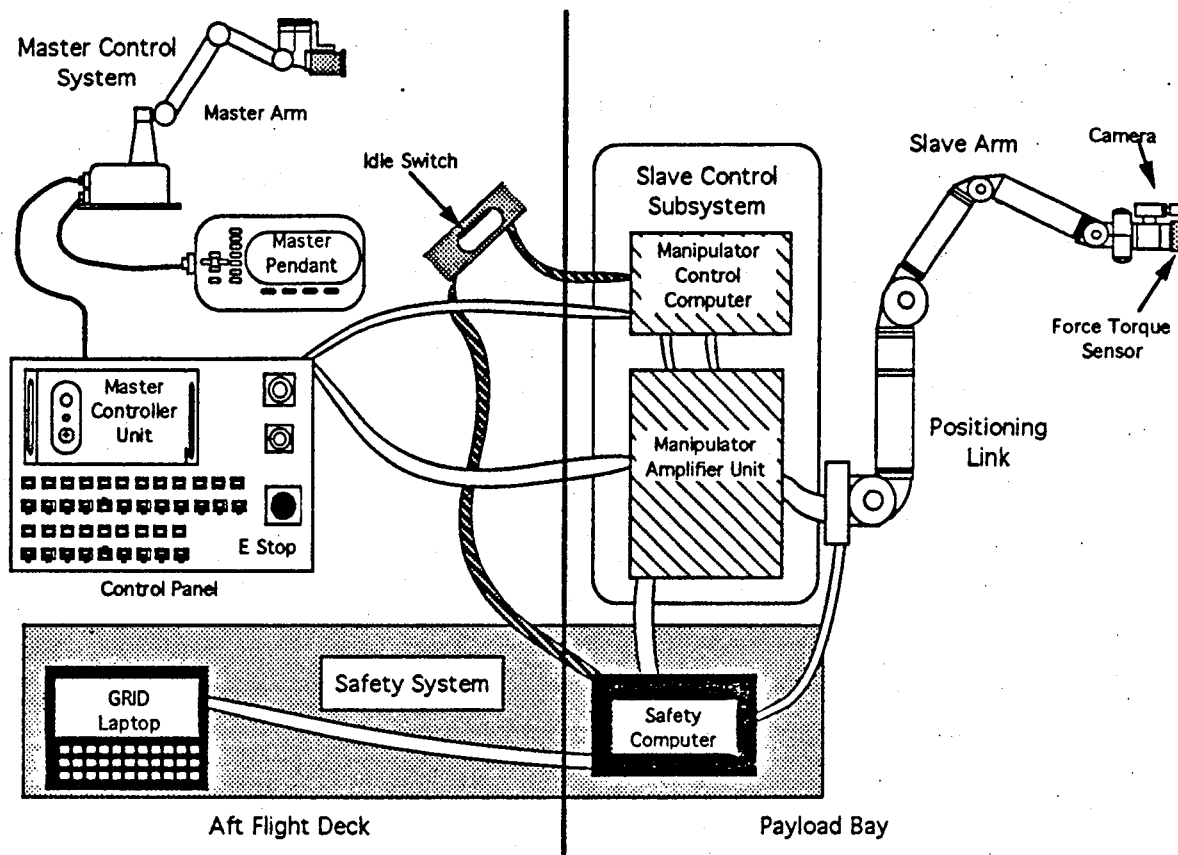


Figure 3 SAT Subsystems

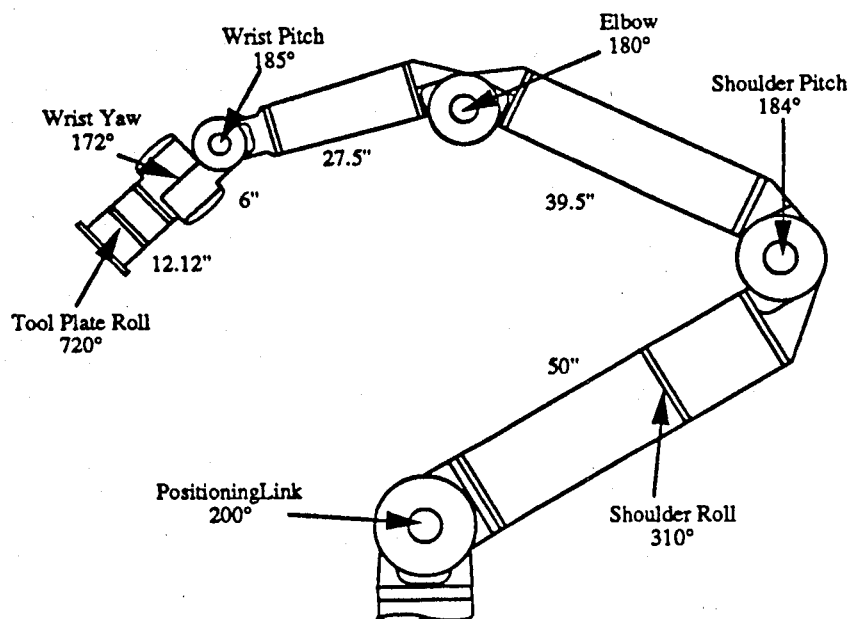


Figure 4. SA/PL Dimensions and Joint Travel

The one degree of freedom Positioning Link is controlled via operator interface keyboard commands, and operates only when the Slave Arm is disabled.

The kinematics are simple, with the three adjacent pitch joints allowing the Operator to mentally separate the position and attitude of the tool: the shoulder and elbow joints provide position; the wrist joints, attitude.

The SAT components (Figure 3) are spaceflight adaptations of existing ground-based designs. The Master Arm is a slightly modified Schilling Development OMEGA from the Titan 7F master/slave system used in undersea systems. The Slave Arm and Positioning Link (SA/PL) are configured to mimic the Schilling Titan 7F Slave Arm kinematics.

To increase the functionality of the SAT, it will be relocatable via the Shuttle Remote Manipulator System (RMS) to various worksite locations where Hot Shoe receptacles are stationed. The hot shoe will provide a releasable electrical and mechanical interface, allowing the SA/PL to be moved to another location, or to be jettisoned in an emergency. A Grapple Fixture will be provided to allow the Shuttle RMS to move the SA/PL. Remote release will be single-fault-tolerant and commanded from the Aft Flight Deck, backup release may also be performed manually via EVA. Inadvertent release will also be two-fault tolerant. The low replacement cost of the slave arm combined with the jettison capability provide a cost-effective means of compliance to the safety requirements for two fault tolerance.

---

## SPACE QUALIFICATION

The SAT components will undergo environmental testing (vibration, thermal/vacuum, and EMI) at protoflight levels. Where necessary, modifications have been made to upgrade designs to protoflight levels. The primary effect has been on the electronics. The RRC Multibus boards in the control computer, for example, had to be replaced with military versions packaged to survive the vibration and thermal environment. A similar version of our protoflight control computer successfully flew on the shuttle for the TSS program. There have also been design changes in the RRC manipulator components to meet outgassing, venting, thermal, and fracture control requirements.

---

## PAYLOAD BAY COMPONENTS

### Slave Arm and Positioning Link

The SA/PL dimensions and joint travel are shown in Figure 4. Figure 5 illustrates the layout on the Flight Support System (FSS), a cross-bay carrier intended for supporting large spacecraft. Components in the Payload Bay are listed below.

All Slave Arm joints have brushless DC motors, operating through a 160:1 harmonic drive. The joint output side is connected through a hollow shaft to a resolver, which reads the angle between the two adjacent links, rather than motor driveshaft angle. In like manner, the strain gauges are mounted to read the output torque of the joint, being mounted at the base of the harmonic drive. Both sensors thus measure the true relationship between the input and output sides of the joint, eliminating the effects of friction and any cogging of the harmonic drives.

The travel for each joint is limited, in order, by software limits, limit switches, and hard stops. Passing a limit switch results in removal of power from the motors and brakes, thus engaging the brakes. The brakes may be remotely disengaged from the Aft Flight Deck (AFD) control panel without powering the motors to allow EVA stowing as a backup.

The SAT is designed to demonstrate its capabilities on the ground as well as to perform on orbit. It is capable of lifting a 20 lb mass in a 1-G environment at any pose within its range of joint travel. The design point for the 0-G case is for a 500 lbm payload.

To provide an interface for an exchange mechanism, tool, and camera, the Slave Arm is designed to be compatible with a variety of exchange mechanisms; it will provide power and data for operation of the exchange mechanism, tool, and camera. The exchange mechanism will be two-fault tolerant to ensure the ability to release tools and ORUs and stow the arm. Several mechanisms are currently under evaluation. Tools will be specified as part of the mission integration in a future program phase.

The maximum joint rates are specified so that no single joint runaway can cause a tool plate velocity in excess of 17 inches per second; this value was chosen as typical of RMS maximum rates.

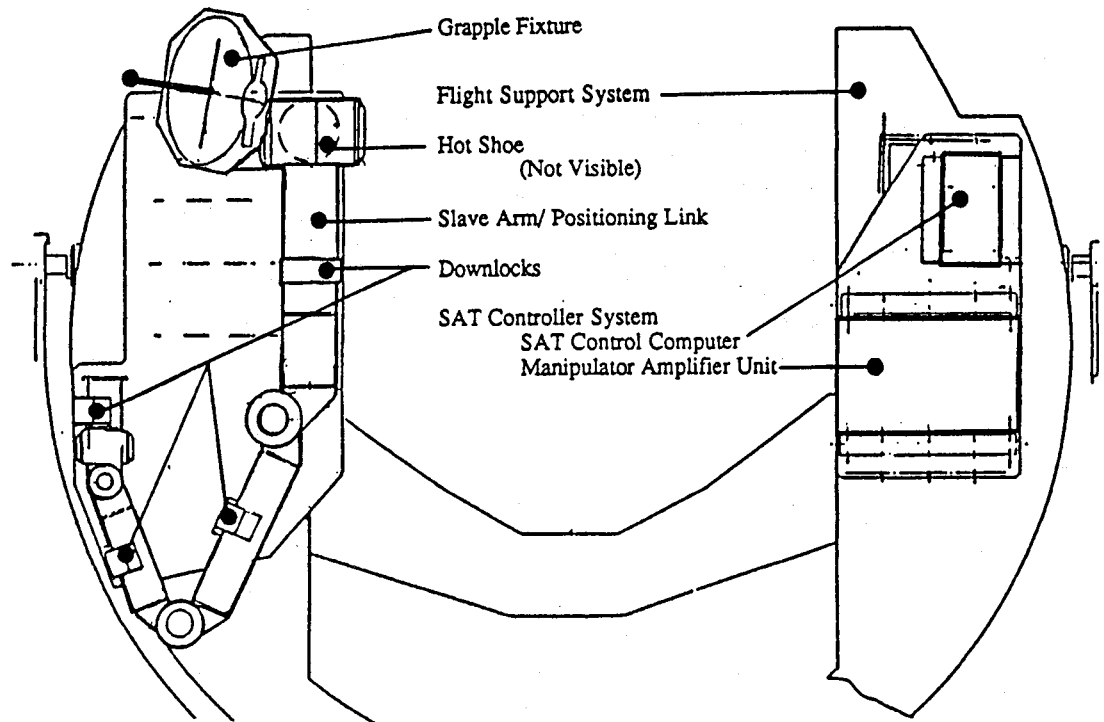


Figure 5. SAT Components Mounted on a Cross-bay Carrier

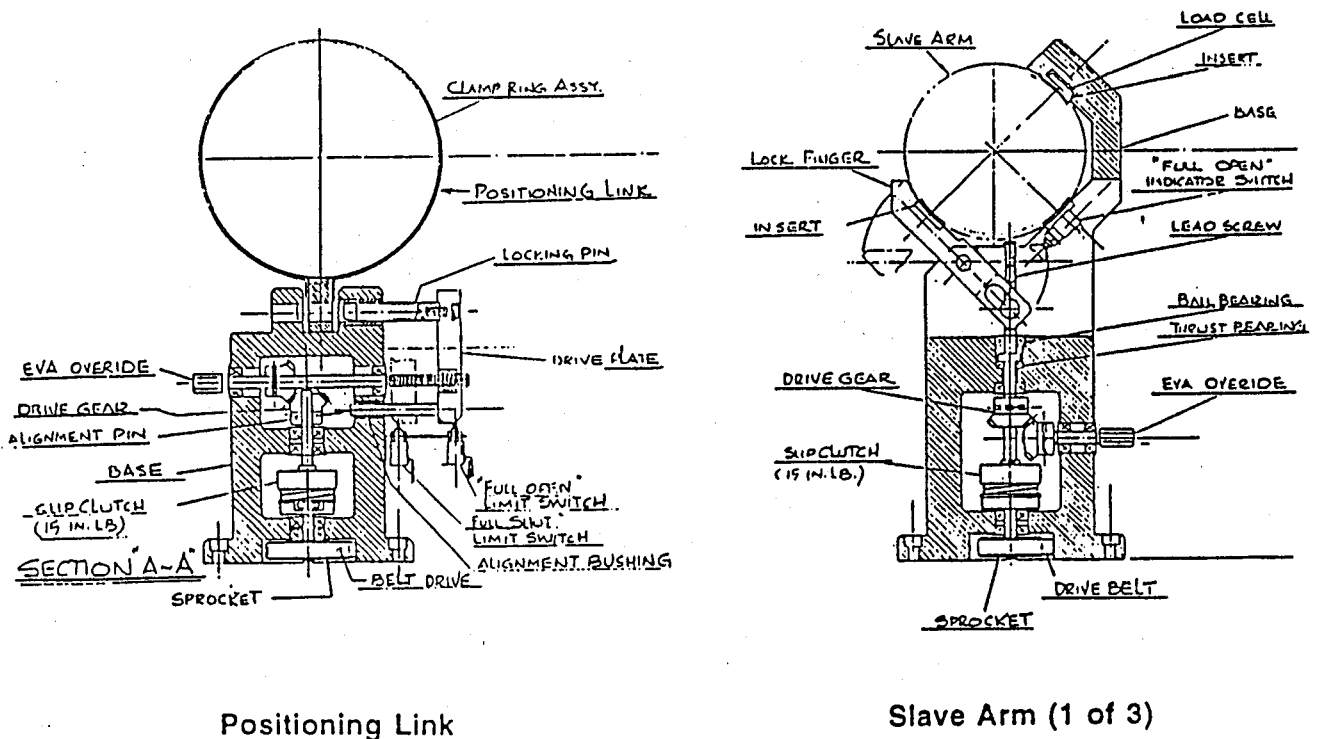


Figure 6. Prototype Downlocks

### **Slave Mounting Assembly**

The Slave Mounting Assembly is the means by which the SA/PL is mounted to its cross-bay carrier, and includes a Mounting Plate, Downlock Mechanisms, Hot Shoe, and Grapple-Hot Shoe Adapter Plate (GHAP).

The Downlocks secure the SA/PL for launch and landing. There is a downlock for each of the four SA/PL links - three for the SA, one for the PL. Figure 6 depicts the prototype downlock design that is to be used both for demonstration and vibration testing; these will be driven via a power wrench. The protoflight downlocks will be driven by a standard FSS Common Drive Unit, and will incorporate load sensors and limit switches to stop power to the drive unit when sufficient torque is read; slip clutches will limit forces on each SA link. Redundant sensors will be incorporated to reliably indicate that the SA/PL is positioned to allow closing the downlock, and that the SA/PL is positively locked after actuation.

### **Slave Controller Subsystem**

The Slave Controller Subsystem (SCS) provides the interface between the master and slave systems, and the control engine and power for the SA/PL. There are two components, the Manipulator Control Computer (MCC), and the Manipulator Amplifier Unit (MAU). These are mounted on a radiator plate, which is in turn mounted on the cross-bay carrier. Both units will be subjected to the appropriate environmental testing for space qualification.

The MCC contains two 80386 based processors for SA/PL control and Master Arm force command generation and another 80386 for communications with the MCS. Slave arm data acquisition is accomplished via MCC resident A/D, D/A, and R/D (resolver to digital) hardware. The MAU contains the motor amplifiers and an analog torque loop compensator for the SA/PL actuators, and watchdog electronics which check the health of the MCC processor boards and secondary power. There are a total of 8 amplifiers, one of which is a backup which may be switched to any individual joint for manually-controlled operation of a joint.

The system is equipped with an Emergency Stop Current Loop which, when broken, will cause the Slave Arm and Positioning Link to become disabled. The Emergency Stop Current Loop can be broken by Operator action, software command or hardware

command. The current loop nodes are shown in Figure 7. Each node is actually a current pass-through which can be broken by the shown input.

---

## **AFT FLIGHT DECK COMPONENTS**

### **Master Controller Subsystem**

The Master Controller Subsystem consists of the modified Schilling components (Figure 8)- Master Arm with a reach of 16 inches, Master Pendant, and Master Control Unit. The Master Arm and pendant are mounted on the master Mounting Assembly; The MCU is inserted into the Control Panel. The MCS components are stowed in a mid-deck locker for launch and landing, packed in a foam material for protection from the loads.

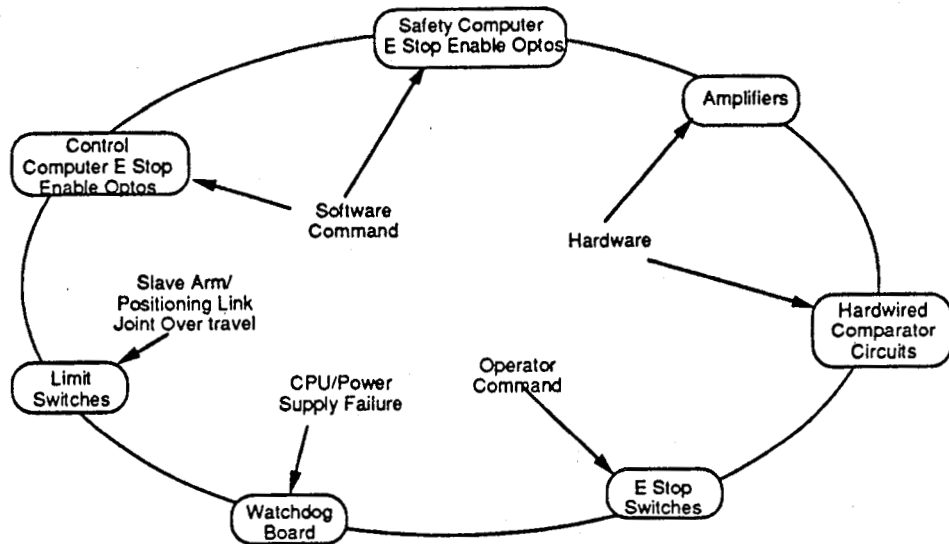
### **Control Panel and Master Mounting Assembly**

The MCS and Control Panel provide the Operator complete control of the system. The Control Panel, mounted in the L11 panel (Figure 8) has control switches for the SA and PL power enables; an Emergency Stop (E-Stop) button, which cuts power to the joint actuators and engages the brakes; and joint brake and limit switch overrides. The latter, in conjunction with controls for a backup single-joint means of operation, allow recovery from some fault conditions which would otherwise cause the Slave Arm to "freeze," preventing stowing.

The L11 panel also provides connections for the Idle Switch, incorporated into a mounting bar attached in the vicinity of the control panel. The Idle Switch is placed so that it provides a stabilizing grasp point for the Operator to react against the Master Arm torques (additional stabilization will be provided by foot straps on the AFD floor). The bar is positioned to allow view of the AFD monitors, as well as a view out the AFD windows, and is designed to allow mounting the master operator interface as well as other tool controls within easy reach of the operator.

In order for the Slave Arm to move, the Operator must depress the Idle Switch on the mounting bar. Releasing the Idle Switch while Slave Arm or Positioning Link motion is being commanded will cause the Slave Arm to decelerate and stop. Motors are not disabled but master and Slave Arm joints are servoed to their current





The Emergency Stop Current Loop is a continuous current loop, which when interrupted causes the slave arm and positioning link to become disabled. The current loop can be interrupted by any of the nodes in the current loop.

Figure 7. Emergency Stop Current Loop Nodes

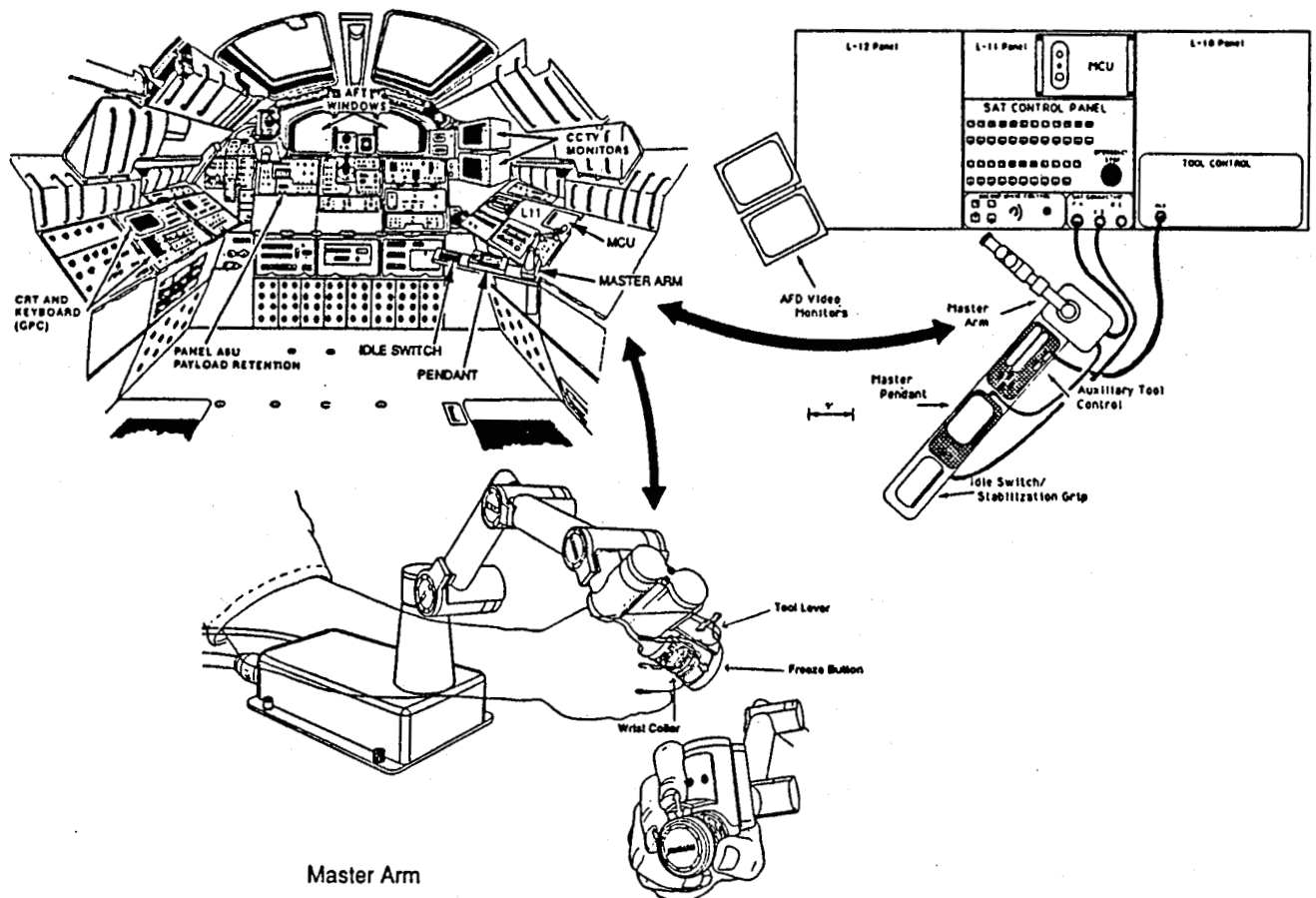


Figure 8. Aft Flight Deck Installation

position. The master and slave arms will maintain their position until the Idle Switch is pressed and the arm is commanded to move again.

---

## **SAFETY ANALYSES AND CONTROLS**

In December 1991, a Technical Interchange Meeting was held with the JSC Payload Safety Review Panel (PSRP). Following some design changes a Phase 0 Safety Review was held in June 1992. The June review was intended to be a Phase 0/1 review of the SAT protoflight hardware and the level of detail for this hardware was commensurate to the Phase 1 level. However, the PSRP argued that since the tasks and ancillary tools not under contract were not well defined, the review would only count as a Phase 0. Following the review, the PSRP chairman commended the technical approach, and proclaimed that we were exceptionally forthcoming with possible fault mechanisms and creative solutions as inhibits.

A Structural Assessment and Hazard Analysis was performed for the SAT to ensure that neither normal operation nor dual failures could result in hazards to the Orbiter, crew, or other critical hardware. To perform these analyses, each subsystem was initially reviewed for its potential to create hazardous functions or effects. The review considered the subsystem design, materials, functions, and interfaces to other subsystems. This section describes the various hazard groups that were considered and the controls against them.

### **Aft Flight Deck Hazards**

The fault tree analysis identified hazard causes within the aft flight deck since the Master Arm and the control panel are used there to operate the system. The Master Arm and control panel used on the aft flight deck can pose hazards to the crew. A mechanical hazard would be uncontrolled motion of the Master Arm; however, as the Master Arm is capable of exerting a maximum of only two pounds force, any injury would be minor.

### **EVA Hazards**

The SAT is not presently planned to be powered during EVA operations. There are also no procedures that require astronaut intervention to return the payload bay to a safe condition except as a third control

(inhibit) to removing the SAT from the bay in the event of a non-operating SAT failure where the SAT obstructs the bay doors or is failed in a position unsafe for landing.

### **Inability to Stow the SA/PL**

If the SAT fails such that it cannot be commanded to its stow position, it could prevent closing the Payload Bay doors, or be unable to withstand the forces of re-entry and landing. In this case, the first option is to use the single-joint backup drive. The second is to disengage the joint brakes to allow an EVA crewmember to manually stow the SA/PL. This can be commanded by overrides available at the Control Panel. These cause power to be applied to the brakes but not to the actuators. An EVA crew member can then manually drive the SA/PL into the downlocks, while the override switches are held down by the Operator. The brakes and downlocks may then be engaged from the Control Panel.

If this proves to be impossible in the available time, the SA/PL may be jettisoned via command from the AFD to release the Hot Shoe. Depending on the Hot Shoe design chosen, jettison may be self-actuated, or may require the RMS to bring the SA/PL out of the Payload Bay. Remote release of the Hot Shoe will be redundant, the Hot Shoe will also provide for release via EVA should remote release fail.

### **Impact During Operation**

Unplanned impacts during operation could cause damage to the orbiter, payloads, or SAT. Such impacts could be caused by failure of the SAT control system, sensors, or actuators; or by Operator error. The SAT system incorporates inhibits against such failures.

The maximum single-joint runaway rates produced by SAT are specified to minimize the possibility of damage to the Orbiter or payloads, and are comparable to those produced by the RMS; they are not optimized for a particular mission. Furthermore, Operator-adjustable limits are incorporated in software in the SCS, commandable via the master operator interface.

If the Operator suspects abnormal operation, he will first release the Idle Switch, which will result in a controlled stop for most faults. The Operator and/or the Monitor may also hit their respective E-Stops, which will shut down all power to the SA/PL, engaging the brakes.

### **Safety System**

The SAT will also have a Safety Computer nearly identical to the MCC. It will monitor SAT's performance and shut down the system in the event certain parameters (Torque, joint rate, etc.) are exceeded. Some of these tests are redundant with those internal to the control computer. The Safety Computer interfaces directly to the Slave Arm analog feedback and control signals, rather than relying on data processes by the Control Computer; this reduces the chance that a computer fault might mask a fault elsewhere in the system.

Additional features being considered include:

- Use of a toolplate force/torque sensor
- Incorporation of proximity sensors distributed along the SA/PL.
- World models of the Orbiter and Payload Bay to establish stay-out zones and automatic reduction in torques and rates when in proximity operations.

The SAT also incorporates independent hardwired adjustable limit-setting hardware. During operation, this hardware operates independent of all system computers, so is not susceptible to any computer faults. When any pre-set limit is exceeded, the SA/PL is disabled.

After operation has been completed the Slave Arm can be disabled by entering a disable command via the operator interface. The Slave Arm can also be disabled using the Emergency Stop Switch, however, it is primarily intended to be used when a quick shutdown is required.

---

## **SYSTEM OPERATING MODES**

The SAT software operates in the following modes, which are commandable by the Operator via the master operator interface in the aft flight deck.

### **System Mode**

The software enters the System mode when powered up, and it may be re-entered by command from the master operator interface, or by an E-Stop commanded by an Operator or by safety software. This mode allows health checks to be performed, and is the only mode that allows parameter updates. No SA/PL motion can occur, as it is unpowered, with brakes engaged.

### **Idle Mode**

The Master and Slave Arms servo to current positions, with brakes disengaged; no commanded motion is possible. This mode is first entered when commanded from the System Mode. The other modes may then be commanded, but will not be entered until the Idle Switch is depressed. It is re-entered when the Idle Switch is released.

### **Teleoperation Mode**

This is, of course, the mode in which most of SAT's work will be done. The Slave Arm responds to commands from the Master Arm. On transition into and out of this mode, both master and slave torques are ramped up and down to prevent step inputs to the worksite and to the operator. Scaled (slave rate less than master rate) or unscaled motion may be chosen via the operator interface. Indexed operation may be initiated by releasing the Idle Switch, moving the Master Arm to a new reference position, and then re-gripping the Idle Switch. These features have been found useful for fine control in proximity to or in contact with the worksite, and provide a flexible means of matching the Slave Arm to the Operator and to the needed task.

### **Automated Task Mode**

A limited number of automated moves will be possible, and are commanded by keyboard input to the Operator interface. These operations still require the Idle switch to be depressed for motion to occur.

- Auto Stow/Unstow -  
SA/PL commanded into and out of the downlocks
- Master to Slave Align -  
Master assumes current pose of Slave Arm
- Slave to Master Align -  
Slave assumes current pose of Master Arm
- Slave to Commanded Position -  
Joint angle values input via operator interface
- Positioning Link is always commanded via  
Operator interface

### **Backup Single-Joint Mode**

In addition to the above modes, which all require software, there is a backup Single-Joint Drive mode available, which is commanded completely via the control panel. A rotary switch is used to choose which joint is to be driven by a separate servo amplifier; another switch controls direction, and a knob the rate.

### **Powerup and Shutdown Operation**

The MCS is powered up via the MCS Power Switch. After the MCS has initialized itself (as indicated on the MCS operator interface screen) the SCS, SA and PL can be powered up. The SCS, Slave Arm and Positioning Link are powered via the appropriate Control Panel power switches.

After the SCS has been powered it performs a self test and checks the status of the Slave Arm and Positioning Link. It communicates all status information to the operator interface. If everything passes, the Operator must verify all operational parameters. Among the status information checked are joint torque, position, temperature and limit switch status.

After all parameters have been verified, the Slave Arm can be enabled. To accomplish this, first the Emergency Stop System must be activated by pressing the Enable E Stop Switch. Next, the Slave Arm can be enabled by entering an enable command via the operator interface then pressing the enable switch on the Control Panel.

After operation has been completed the Slave Arm can be disabled by entering a disable command via the operator interface. The Slave Arm can also be disabled using the Emergency Stop Switch, however, it is primarily intended to be used when a quick shutdown is required. Note that the Idle Switch stops motion, but does not disable the arm.

---

## **POTENTIAL ENHANCEMENTS USING EXISTING TECHNOLOGY**

Since the flight-qualified Servicing Aid Tool (SAT) mechanism and its control system are functionally identical to NASA's RRC laboratory units, many of the technologies that have been developed by NASA can be applied directly to the SAT to increase its capabilities for satellite servicing with minimum risk and expense. Five specific enhancements being considered are listed, as follows, in proposed order of implementation:

### **1. Addition of a High-Level Telerobotic Control System**

One of several available versions of a high-level telerobotic control system (JSC, GSFC, JPL) could be implemented on new computer boards added to the

existing SAT control system to provide programmable operation, 6-DOF kinematic cartesian control (i.e., the ability to command straight line moves) and a more powerful user interface. Space for such additional boards is already provided in the current SAT control hardware arrangement.

### **2. Addition and Evaluation of Alternative Hand Controllers**

The Schilling replica master force-reflecting hand controller currently used in the SAT system is but one of several alternatives available. With the implementation of the above-described high-level controller and 6-DOF kinematics, two other types of hand controls which could offer advantages in certain SAT operations and may be preferred by the astronaut users can easily be interfaced and compared. Specifically, it is felt that a pair of standard 3-DOF rate controllers should be tried (as used to operate the RMS today), along with a 6-DOF hybrid rate/force controller from Cybernet Systems. Both types of hand controller have already been procured by NASA and could be made available. In general, it is anticipated that the ability to perform straight line moves with a rate controller—essentially to “fly the hand” of the SAT—will greatly simplify certain teleoperated tasks like extracting ORUs.

### **3. Addition of Impedance Control Software**

Implementing existing impedance control software on the SAT will give the operator the ability to regulate electronically the apparent stiffness of the manipulator arm as it executes a contact operation. Essentially, this feature will permit the manipulator to control the forces and moments it exerts when mating two rigid parts (as in ORU insertion). Impedance control is particularly advantageous when using a rate controller to perform contact operations, since tool/workpiece reaction forces can be controlled (and limited) with great accuracy.

### **4. Addition of 6+1-DOF Kinematics**

A 7-jointed manipulator arm affords an infinite number of arm postures for any given position and orientation of the tool (and the payload). Like the human arm, it can thus work around objects in the work space without collisions, providing significantly more capability to perform complicated manipulation tasks in cluttered environments. The current SAT slave arm has six degrees of freedom (one joint is also provided on the positioner link that supports the slave arm). To increase dexterity, it is recommended that a seventh joint be

added to the slave arm (an "elbow roll" joint), giving the operator the ability to change the elbow orientation, as a separately controlled joint, during operations. This new seventh joint would only be used, in this case, for arm reconfiguration and would not be active during the execution of tool-handling tasks. Once the operator has selected a preferred elbow posture, the slave arm would be controlled as a 6-DOF system.

#### **5. Addition of Redundant 7-DOF Kinematics**

With no further changes to the 6+1-DOF slave arm mechanism beyond those described above, more powerful redundant control software could be added to the SAT system if a prospective servicing application demands the enhanced capabilities afforded by active redundancy. Benefits include proximity sensor-driven, reflexive collision avoidance, by which the arm automatically changes its posture to avoid collisions with objects in the workspace, and automatic selection of the optimal arm pose to avoid singularities and improve leverage.

---

## **PROGRAM STATUS & CONCLUSION**

The protoflight slave arm and controller are currently undergoing verification testing at Robotics Research Corporation. This hardware is due to ship to the GSFC by mid-August. Upon delivery, the master/slave communications software, gravity model, and force feedback software will be ported over to the protoflight controller for integration of the full-up master/slave system. The protoflight system will then proceed to environmental testing expected to be completed around the end of the calendar year. In January 1994, the basic SAT will be qualified for the rigors of space flight.

Future phases of the program are anticipated to continue ground demonstrations and to include the incorporation of selected enhancements. These enhancements will primarily be chosen to best augment the SAT's capabilities to perform a range of servicing tasks directed toward the second Hubble Space Telescope (HST) servicing mission. Current mission analyses for the first servicing mission support the postulate that the SAT will enhance astronaut tasks and timelines. The Servicing Aid Tool will provide a telerobotic complement to significantly enhance extravehicular capabilities.

#### **Reference**

Pullen, J. L., et al, "The Servicing Aid Tool," Cooperative Intelligent Robotics in Space III, Boston MA, November 15-20, 1992



# **UNDERSEA SERVICING ANALOGS LESSONS LEARNED FOR SPACE SERVICING**

**OCEANEERING SPACE SYSTEMS (OSS)**

**John O'Donnell**

**October 19, 1993**



# **OCEANEERING SPACE SYSTEMS (OSS)/OCEANEERING INTERNATIONAL**

## **BACKGROUND**

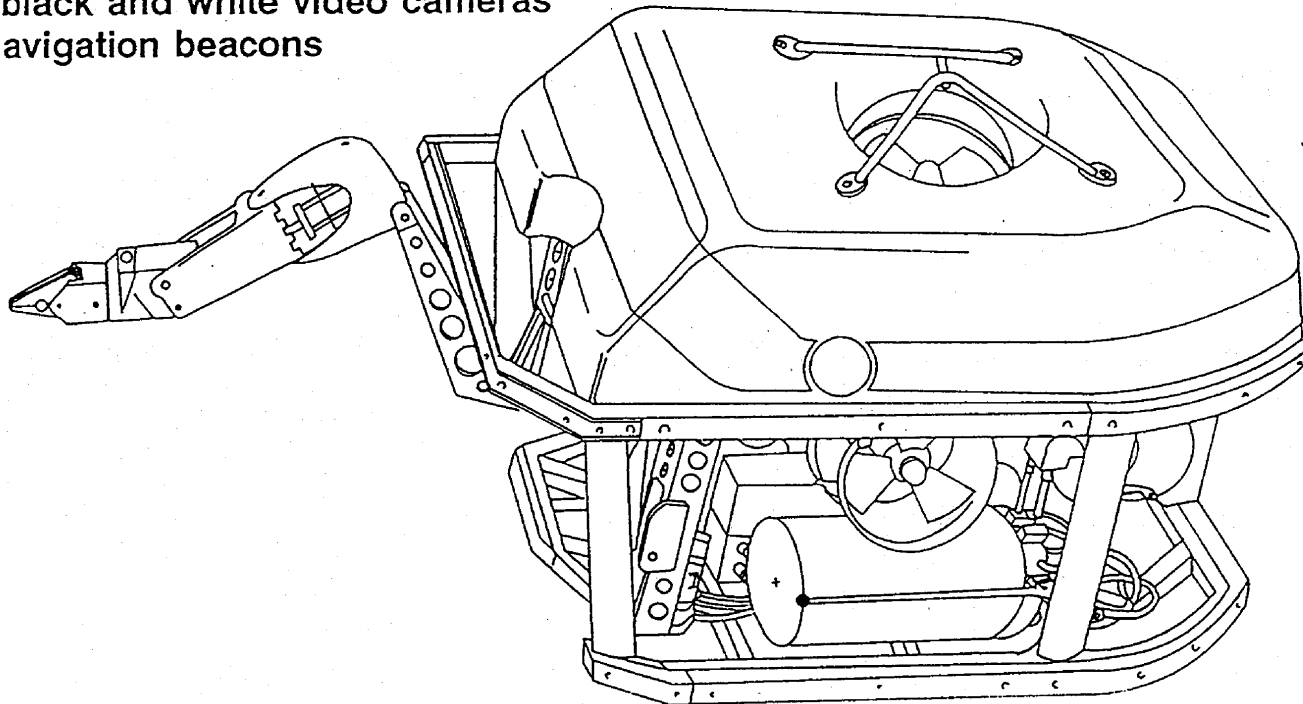
- **Oceaneering Space Systems is a division of Oceaneering International Inc. (OII), one of the world's largest and oldest subsea services company**
- **Oceaneering owns and operates:**
  - **72 deep, mixed gas/saturation diving systems (analogous to EVA)**
  - **27 atmospheric JIM & WASP diving suits (analogous to the MMU)**
  - **70+ Remotely Operated Vehicles (ROVs are undersea telerobots)**
  - **Offshore survey, navigation (GPS), and positioning systems**
  - **Structural member and pipeline inspection NDE/NDT equipment (OII division Solus-Schall has X-ray pipecrawlers, ultrasonics, etc.)**
  - **8 vessels supporting offshore operations**





## REMOTELY OPERATED VEHICLE (ROV)

- ROVs are underwater telerobotic work systems designed to allow surface operators to conduct inspection and/or work tasks in the subsea environment.
- Features:
  - umbilical for power, video, and telemetry
  - power pack and propulsion units
  - manipulators and tools
  - scanning sonars
  - color and black and white video cameras
  - acoustic navigation beacons



Oceaneering HYDRA™ Remotely Operated Vehicle (ROV) with extended 7-function manipulator



## **BACKGROUND (Cont.)**

- **OCEANEERING is an industry leader in both manned and telerobotic work systems operations with 30 years of underwater servicing experience.**
  - Over 3,500,000 hours of manned diving operations
  - Over 350,000 hours of teleoperated vehicle operations (ROV)
- **Many of the lessons learned in our subsea technology development and offshore operations are directly applicable in the space servicing.**
- **NASA recognized the analogies, and six years ago we entered into contracts supporting both NASA and the commercial aerospace industry.**
- **OCEANEERING SPACE SYSTEMS supports NASA in the design and development of:**
  - Manned Spaceflight Hardware (EVA tools and equipment)
  - Robotic tools, end effectors, and interfaces (Space Station)
  - Cryogenic life support equipment (Neutral buoyancy PLSS)



## **SUBSEA REMOTE SERVICING/SALVAGE TASKS**

- **Undersea Oil and Gas Exploration & Production (to 7500 ft.)**
  - oil & gas exploration equipment installation, inspection, servicing, and repair
  - oil & gas production equipment construction, inspection, maintenance, and repair
  - tubular structure and pipeline inspection, NDE, repair
  - offshore oilfield bottom survey, equipment salvage and recovery
- **U.S. Navy (to - 20,000 ft.)**
  - world-wide deep ocean search
  - deep ocean salvage & recovery
  - cable inspection, burial, and repair
- **Telecommunications Industry (to - 6000 ft.)**
  - transoceanic cable burial and retrieval
  - cable inspection and repair



# **EVOLUTION OF OFFSHORE OILFIELD EQUIPMENT SERVICING**

## **MAINTENANCE**

- Oil companies commissioned "diverless systems" so called because they had redundant, fail-proof features designed to eliminate human intervention. These systems were deployed in deep water offshore oilfields.
  - Like most complex systems, these systems did encounter failures that exceeding the fault-tolerant capabilities of the design.
  - Since the equipment was designed to be fail-proof and not serviceable, it was difficult or impossible to repair or service in the field when it did fail.
  - Oil companies were forced to resort to contingency subsea maintenance strategies when functions degraded or failed.
  - Contingency operations were found to be time-consuming, expensive, and risky.



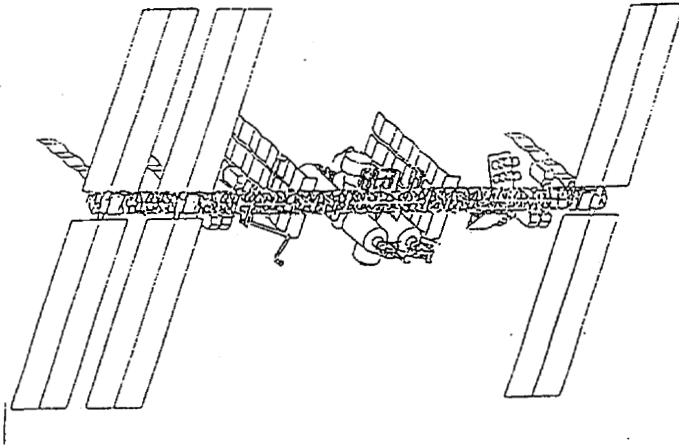
# **EVOLUTION OF OFFSHORE OILFIELD EQUIPMENT SERVICING**

## **MAINTENANCE**

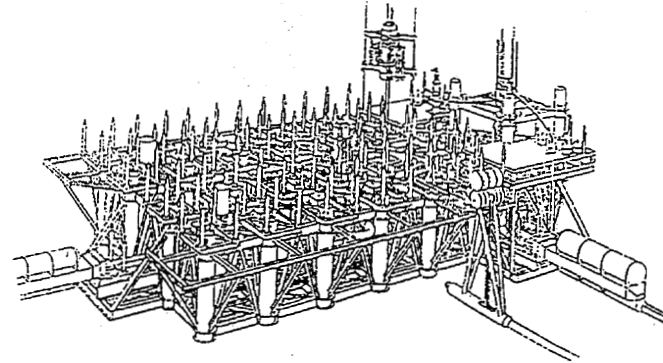
- Years of operational experience established that equipment would need maintenance, thus had to be designed to accommodate the humans or machines working on it.
  - Retrofits are costly and therefore not attractive to oil company management.
  - There is a cost-effective balance between redundancy (fault-tolerance) and serviceability.
  - Incorporating common interfaces and standardizing them early in the design cycle, as well as designing tasks and procedures for simplicity, enabled effective maintenance for the newer generations of subsea oilfield equipment.

## OFFSHORE OILFIELD FACILITIES

- A majority of offshore facilities are extremely large and complex truss structures similar to the Space Station Freedom design.



Space Station Freedom



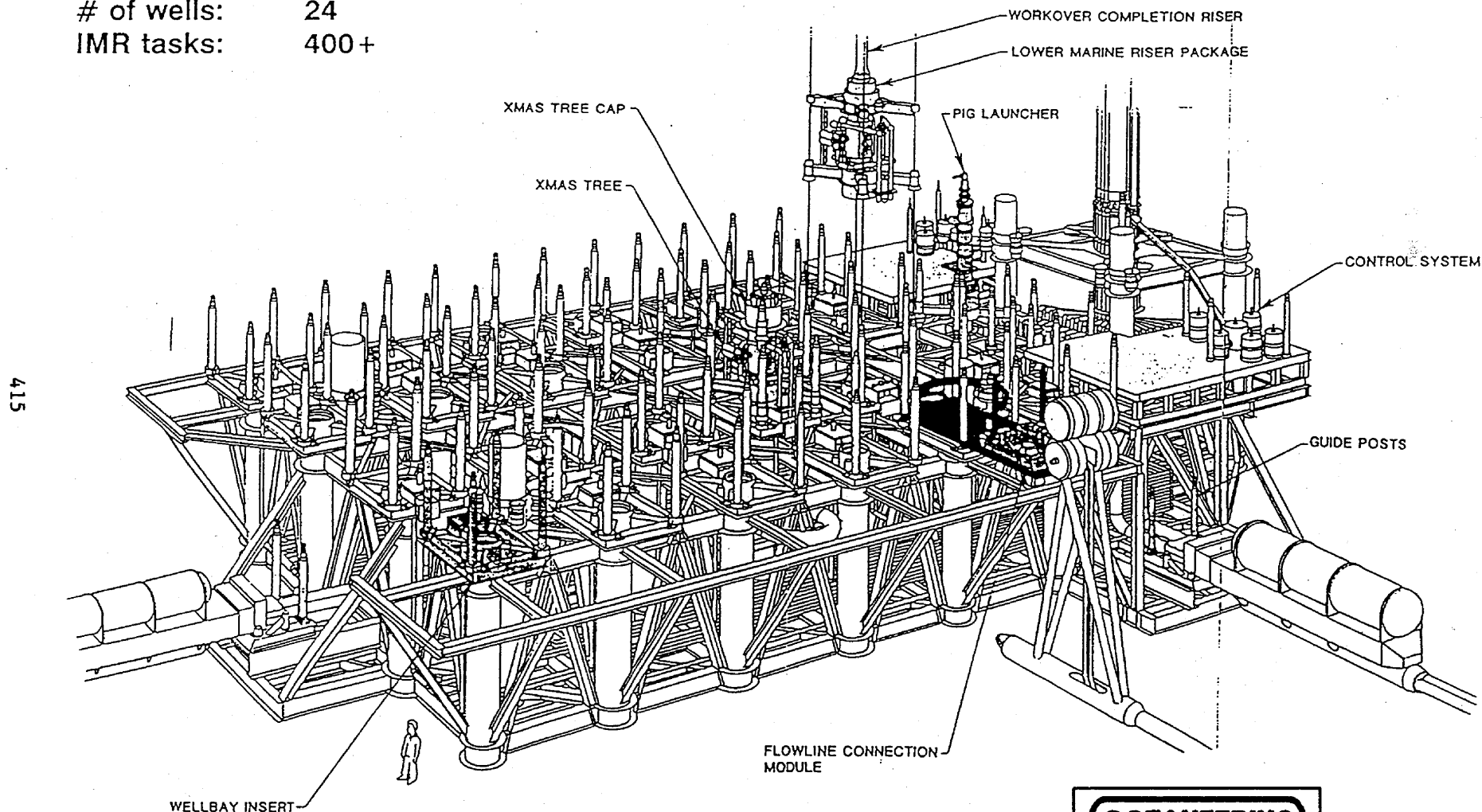
Subsea Oilfield Production System

- Both require phased logistics support in order to transport, assemble, and install materials to a remote hostile environment worksite.
- Operational costs are in the multi-billion dollar range over the life of these facilities (these life-cycles average from 20 to 30 years).
- Facilities must be inspected, maintained, and repaired using sophisticated, expensive equipment by highly trained personnel working in a potentially hazardous surroundings.



# PLACID GREEN CANYON SUBSEA PRODUCTION SYSTEM

Size: 100' x 200'  
Depth: 1500 FSW  
Location: Green Canyon, Gulf of Mexico  
# of wells: 24  
IMR tasks: 400+



## DESIGNING SUBSEA EQUIPMENT FOR SERVICING

- Establish an integrated system design methodology, identify servicing requirements as early as possible in the system's design cycle.
  - perform task analyses
    - determine task requirements, constraints, and procedures
    - identify work system capabilities
    - create IMR task scenarios
  - model or mockup task equipment
  - perform simulations of task scenarios
  - identify disconnects and incompatibilities
  - correct deficiencies in the design early



## DESIGNING SUBSEA EQUIPMENT FOR SERVICING

- Establish servicing task and equipment standards
  - demonstrated servicer capabilities
  - system architecture and resource support capabilities
  - worksite accommodations
  - task designs
  - work system and equipment interfaces
  - tools and support equipment

# EVOLUTION OF OFFSHORE OILFIELD EQUIPMENT SERVICING STRATEGIES

## REPAIR

- Repairing damaged subsea oilfield equipment generally meant halting expensive exploration or production operations.
  - When possible, the entire piece of subsea equipment was retrieved to the surface for servicing onboard the rigs.
  - If retrieval was not feasible, then complex saturation diving equipment (analogous to EVA operations) and possibly underwater welding habitats were mobilized to effect the repair.
- The repairs generally not only incurred the hit of downtime expense (and subsequent loss of revenue), but required expensive subsea servicing operations to repair the problem.

# EVOLUTION OF OFFSHORE OILFIELD EQUIPMENT SERVICING STRATEGIES

## REPAIR

- Once again, operational experience dictated a change of strategy and design approach.
  - Subsea oilfield equipment designers began standardizing their packaging, interfaces, and procedures.
  - Functional units were packaged into modules that could be removed and replaced from the surface without underwater intervention. (analogous to docking or berthing operations in space)
  - Failure prone components were redesigned for easy removal and replacement by subsea work systems. (analogous to ORUs)
  - The equipment interfaces were standardized, well marked, provided with status indicators, and made accessible to the work systems used for repair.



## LESSONS LEARNED

- 30 years of offshore operational experience established that equipment to be assembled, maintained, and serviced in hostile environments must be designed to accommodate the systems servicing the equipment.
  - Retrofits are costly and therefore not always attractive to program management.
  - However, there is a cost-effective balance between redundancy (fault-tolerance) and serviceability when the servicer's capabilities are understood and demonstrated.
  - Incorporating commonality, standardizing tools and interfaces, and understanding the potential servicing tasks early in the design cycle permits designing tasks for simplicity.
  - Operational experience showed that performing servicing tasks successfully requires a mix of work system capabilities, manned and telerobotic.



## LESSONS LEARNED

- **Designing a complex system for servicing in a hostile environment requires a thorough knowledge of the system's functions, failure modes, logistics support requirements, the repair and servicing tasks, work system capabilities, and the environment in which it operates.**
- **The offshore service industry has been able to effectively integrate diving systems and/or telerobotic systems with the newer generations of subsea oilfield equipment.**
  - **As a result of our offshore oilfield work system tooling and interface designs, deep water diving (saturation diving) is operational to 1000 FSW.**
  - **Teleoperated ROVs have now become an indispensable resource within the offshore oil industry. Teleoperated maintenance and repair missions are taken for granted in the offshore petroleum, military, and telecommunications industry, worldwide.**



# **MISSION ANALYSIS**

**FOR**

## **SMALL ELV-BASED, IN-SPACE OPERATIONS**

**Davy A. Haynes,  
Scott Baune,  
John Lussier &  
Mike Rice**

**Space Technology Initiative Office  
NASA Langley Research Center**

**SELV-Based In-Space Operations Workshop  
Newport News, Virginia  
October 18-19, 1993**

# **Mission Analysis Overview**

- Survey of Candidate Missions**
- Definition of Mission Categories and Types**
- Mission Type Characterization**
- Preliminary Mission Analysis**
- Conclusions and Recommendations**



# **Survey of Candidate Missions**

## **ARABSAT 1A**

**Type: Communications**

**Owner: ASCO/Saudi Arabia**

**Manufacturer: Space Systems-Loral**

**Launched: 8 Feb 85 (Ariane)**

**Mass: 592 kg on-station @ BOL**

**Orbit: 19 deg E Geostationary**

**Design Life: 7 years**

**Failure: About one month after launch, power to two ACS gyros failed causing North-South station keeping to be exercised manually. The spacecraft, although partially functional, was declared an in-orbit spare and \$75 M insurance was paid.**

**Mission Classification: Repair (power distribution) of a partially functional asset.**

# **Survey of Candidate Missions**

## **INSAT 1C**

**Type: Communications**

**Owner: Indian National Satellite Systems**

**Manufacturer: Ford Aerospace (SS/Loral)**

**Launched: 21 Jul 88 (Ariane)**

**Mass: 1152 kg at launch, 650 kg on-station @ BOL**

**Orbit: 93.5 deg E Geostationary**

**Design Life: 7 years**

**Failure: Power system failure due to a isolation diode short on a solar panel. Communications lock was lost Nov 88 and the spacecraft was abandoned, resulting in an insurance payoff of \$70 M.**

**Mission Classification: Repair (solar panel replacement) of asset in geostationary orbit. Functional status unknown.**

# **Survey of Candidate Missions**

## **INSAT 1A**

**Type: Communications**

**Owner: Indian National Satellite Systems**

**Manufacturer: Ford Aerospace (SS/Loral)**

**Launched: Apr 82 (Delta)**

**Mass: 1152 kg at launch, 650 kg on-station @ BOL**

**Orbit: Geostationary**

**Design Life: 7 years**

**Failure: Abandoned after 5 months when attitude control propellant was exhausted.  
\$70 M insurance was paid.**

**Mission Classification: Refuel of otherwise fully-functional geostationary satellite.**

# **Survey of Candidate Missions**

## **Superbird A**

**Type: Communications**

**Owner: Space Communications Corp. of Japan**

**Manufacturer: Ford Aerospace (SS/Loral)**

**Launched: 5 Jun 89 (Ariane IV)**

**Mass: 2492 kg at launch, 1505 kg on-station @ BOL**

**Orbit: 158 deg E geostationary**

**Design Life: 10 years**

**Failure: Lost most of its station keeping oxidizer on Dec 90 possibly due to a command error. Commercial operations ended and \$170 M in insurance was paid.**

**Mission Classification: Refuel (oxidizer) of otherwise fully-functional valuable asset.**

# **Survey of Candidate Missions**

## **Palapa B2**

**Type: Communications**

**Owner: Perumtel (Indonesia)**

**Manufacturer: Hughes**

**Launched: 4 Feb 84 (Shuttle)**

**Mass: 1240 kg at launch, 652 kg on station @ BOL**

**Orbit: 108 deg E Geostationary**

**Design Life: 8 years**

**Failure: Initially stranded in 237 X 1046 km orbit after failure of PAM-D GTO insertion stage. Moved to 1207 km orbit then lowered to Shuttle altitude using all reserve propellant. Recovered by Shuttle in Nov 84 and sold to Sattel Technologies for \$18-21 M. Re-launched Apr 85 after a \$7 M refurbishment by Hughes. Resold to Indonesia for \$137.5 M.**

**Mission Classification: Reboost of valuable asset in improper orbit.**

# **Survey of Candidate Missions**

## **Westar VI**

**Type: Communications**

**Owner: Western Union**

**Manufacturer: Hughes**

**Launched: 4 Feb 84 (Shuttle)**

**Mass: 1100 kg at launch, 582 kg on-station @ BOL**

**Orbit: Geostationary**

**Design Life: 10 years**

**Failure: Stranded in 266 X 1059 km orbit after failure of PAM-D GTO insertion stage. Boosted to 1060 X 1066 km by the AKM to prevent atomic oxygen damage, then lowered to Shuttle altitude for retrieval. Later refurbished and relaunched as AsiaSat 1 by Asia Satellite.**

**Mission Classification: Reboost of valuable asset in improper orbit.**

# **Survey of Candidate Missions**

**et al**

**Hipparcos (Aug 89): ESA science spacecraft stranded by booster failure.**

**STTW-T1 (Jan 84): Chinese communications satellite stranded by booster failure.**

**Telecom 1B (May 85): French communications satellite drifted from GEO due to RCS failure.**

**TDF-1 (Oct 88): French communications satellite loses transponder due to electrical arcing via a propellant leak.**

**TDF-2 (Jul 90): French communications satellite losses two traveling wave tube amplifiers when inadvertently shutdown by a safety mechanism.**

**TV-Sat 1 (Nov 87): German communications satellite suffered from failed deployment of a solar panel.**

**BS-2 (Jan 84): Japanese communications satellite suffered from loss of two out of three transponders.**

**BS-3 (Aug 90): Japanese communications satellite suffered from failure of one out of four solar panels.**

# Definition of Mission Categories and Types

## Repair

### Definition

Overcoming a dysfunctional component, system, or spacecraft to attain a fully-function spacecraft; or to significantly improve the spacecrafts functional status.

### Subcategories

**Restoration:** to return the dysfunction system to service by repairing (fixing) the failure.

**Replacement:** to physically replace the dysfunction component with a new unit.

**Supplement:** to bypass the dysfunctional component by supplying a new unit to provide the function without physical replacement.



# **Definition of Mission Categories and Types**

## **Refuel**

### **Definition**

**Replenish a satellite's supply of fluid consumables by refilling the S/C's propellant/pressurant tanks, or by supplemental tanks.**

### **Subcategories**

**RCS fuel/oxidizer: resupply fuel and/or oxidizer for the S/C's reaction control system.**

**Pressurant: resupply pressurant gases (N<sub>2</sub>, He, etc.) used to pressurize S/C propellant tanks.**

# Definition of Mission Categories and Types

## Deorbit/Disposal

### Definition

Perform a propulsive maneuver to deorbit or dispose of a satellite which is no longer needed or functional.

### Subcategories

**Deorbit:** Propulsive maneuver is such that the satellite is destroyed upon reentry over an unpopulated area. *Primarily for LEO spacecraft.*

**Disposal:** Propulsive maneuver is such that the satellite is moved to a safe orbit for deactivation. *Primarily for GEO spacecraft.*

# **Definition of Mission Categories and Types**

## **Payload Delivery/Recovery**

### **Definition**

**Deliver and/or recover specialized payloads to assets already in orbit.**

### **Subcategories**

**Critical hardware delivery (Space Station).**

**Critical crew recovery vehicle (Space Station).**

# **Definition of Mission Categories and Types**

## **Retrieval**

### **Definition**

**Safely return a spacecraft to Earth for repair, refurbishment, salvage, or study.**

### **Subcategories**

#### **Direct Recovery**

**Recovery via STS: lower a spacecraft to an altitude that is accessible by the Shuttle.**

# **Definition of Mission Categories and Types**

## **Reboost**

### **Definition**

**Propulsively reposition a satellite into a new orbit.**

### **Subcategories**

**LEO Reboost: raise a spacecraft's orbit to compensate for and prevent orbital decay.**

**GTO Insertion: perform GTO insertion for stranded GEO satellite. Might also have to perform subsequent apogee (circularization and inclination change) maneuver.**

# Mission Type Characterization

Candidate missions were separated into LEO, MEO, and GEO to allow a characterization of mission types based upon SELV performance.

LEO includes spacecraft at altitudes up to 800 km at any orbital inclination.

- HST (Hubble Space Telescope)
- EOS (Earth Observing System) satellites
- SSF (Space Station Freedom)
- Nimbus weather satellites

MEO includes satellites at altitudes up to 10,000 km at any orbital inclination.

- GPS (global positioning system) satellites

GEO includes all geostationary satellites--36,000 km equatorial.

- Nearly all communications satellites

# Mission Type Characterization

Available SELV's, with reasonable assumptions for growth, bound the performance envelope of interest.

- Pegasus/Taurus (Orbital Sciences)
- MSLS (Martin Marietta)
- Conestoga (EER Systems)
- LLV1 (Lockheed)
- ORBEX (CTA)

Guidelines [performance] for the subsequent analysis.

- LEO (<800 km): not more than 2,000 kg
- MEO (800-10,000 km): 500-1,000 kg
- GTO (36,000 km apogee): not more than 500 kg

Note that all missions assume an automated rendezvous and docking capability.

# **Preliminary Mission Analysis**

## **Approach and Assumptions**

**Conceptualized various front-end spacecraft "kits" which would be tailored to suit the different mission categories.**

**Spacecraft kits would be ship-and-shoot, to minimize ground operations and preparation time.**

**Buses for the spacecraft kits would be short-lived (in orbit) to minimize development and testing.**

**Propulsion systems would be based on either solids or storable liquids and restricted to motors and engines already available.**

**Preliminary analysis aimed at eliminating those missions which would be improbable from a performance standpoint; and to shed insight on those missions feasible from a performance standpoint.**

**Analysis used to identify potentially attractive categories for subsequent conceptual mission design and analysis.**



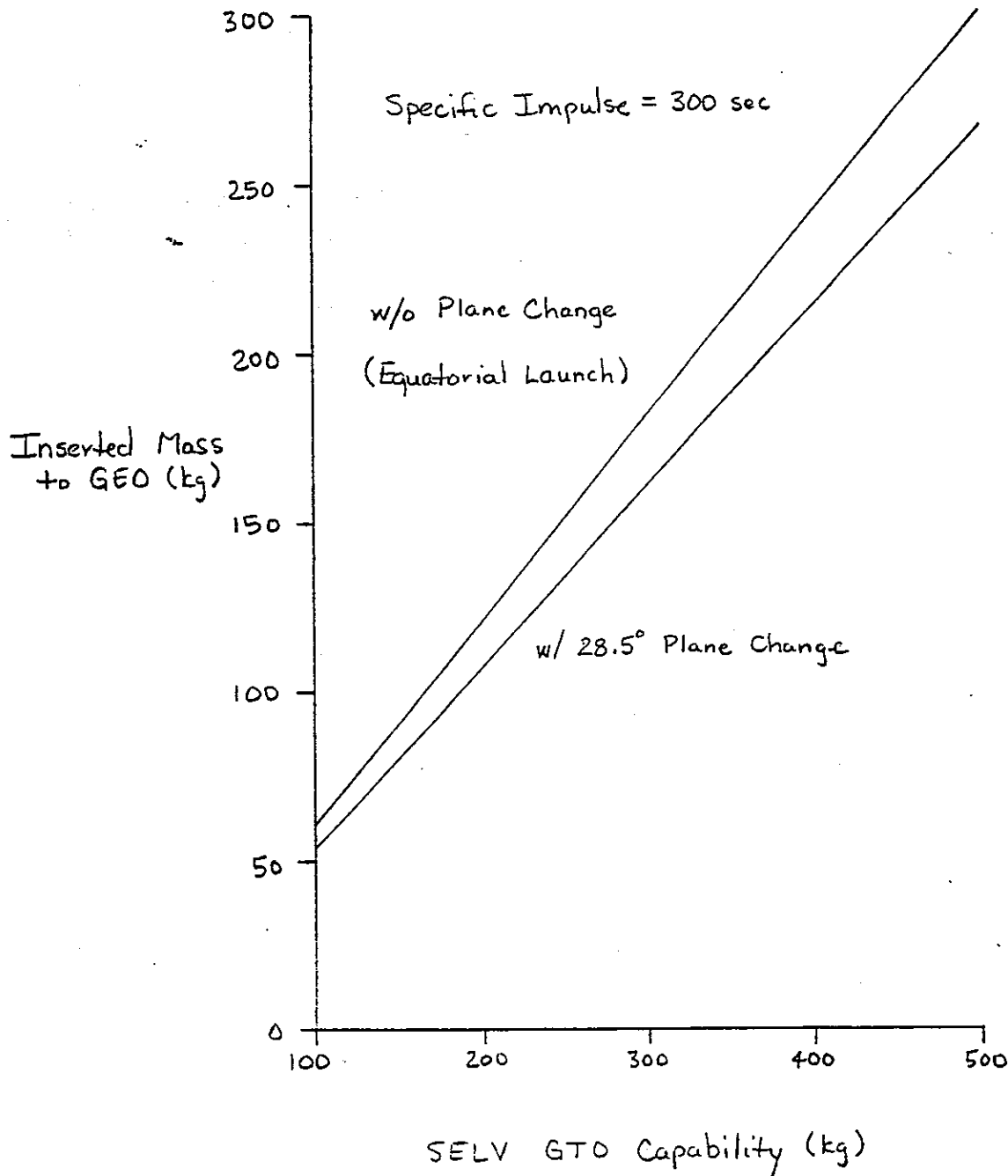
# **Preliminary Mission Analysis**

## **Repair--*Fix, Replace, or Supplement***

**Assuming a SELV places a repair "kit" into a GTO by direct injection, how much mass can be placed into GEO?**

- Propulsion system based upon small liquid bi-props with a 300 s specific impulse.**
- Overall kit mass is too small to make realistic estimates of what payload fractions might be.**
- SELV insertion accuracies may make rendezvous at GEO complex and expensive.**
- The good news is that SELV launch from near the equator can increase payloads to GEO by about 20%.**
- Usable payloads to GEO will be small (10's of kg).**
- Usable payloads to MEO will be on the order of 100 kg.**
- Usable payloads to LEO can be nearly 1,000 kg.**

# GEO Capability



# **Preliminary Mission Analysis**

## **Refuel--*Replenish RCS Propellant***

**Replenishing a satellite's consumables at GEO appears to be possible, particularly if the kit's own tanks are used.**

- Mass of propellant required by most GEO satellites for station keeping is on the order of 10's of kg for several years of operation.**
- Most GEO satellites utilize bi-prop thrusters which are compatible with the propellant of the kit itself.**
- Dedicated tanks for the refuel propellants would not be required; thus increasing the "payload" margin.**
- Since a refuel kit for GEO must be able to perform its own circ and rendezvous maneuvers, the same bus would easily be able to reach any LEO/MEO satellite.**
- LEO, MEO, and GEO satellites all share similar station keeping propellant needs.**

# **Preliminary Mission Analysis**

## **Delivery/Recovery**

**The only identified mission is Space Station logistics--in particular delivery of critical items needed for repairs that cannot wait for a Shuttle flight that may be several months away.**

- An air-launched SELV, such as Pegasus, has the added advantage that orbital plane alignment can be obtained using the carrier aircraft--large launch windows.**
- Recovery of payloads from the Space Station would also be possible, but is a much bigger problem.**
- Perhaps a better use of a delivery kit, after it has performed its initial mission, would be to dispose of Space Station refuse by reentry incineration.**

# **Preliminary Mission Analysis**

## **Retrieval**

**Retrieval, or salvage of high-value spacecraft at the lower end of the SELV cost spectrum. Unfortunately, direct retrieval by an SELV-launched kit is not feasible for most satellites due to their size and mass.**

- Retrieved satellite must be protected from reentry heating, aeroloads, and g-loads.**
- Must be soft-landed by some means.**
- An alternative for high-value payloads would be to use the kit to lower satellites to a Shuttle-accessible orbit for pick-up as a targets of opportunity.**

# **Preliminary Mission Analysis**

## **Deorbit**

**Deorbit of satellites in LEO is easily achievable for even very large satellites due to the low energy requirements for this type of mission.**

## **Disposal**

**Disposal of GEO satellites may be accomplished by moving the unwanted satellite to a slightly higher orbit with small, two-burn propulsive maneuvers.**

- The residual propulsive capability after a kit reaches GEO is extremely limited, especially for the larger comm. satellites.**
- Fortunately, the propulsive requirements are small at this distance--even to move a satellite out 1,000 km.**
- Similar to a refueling mission except that the kit would use its residual propellant.**

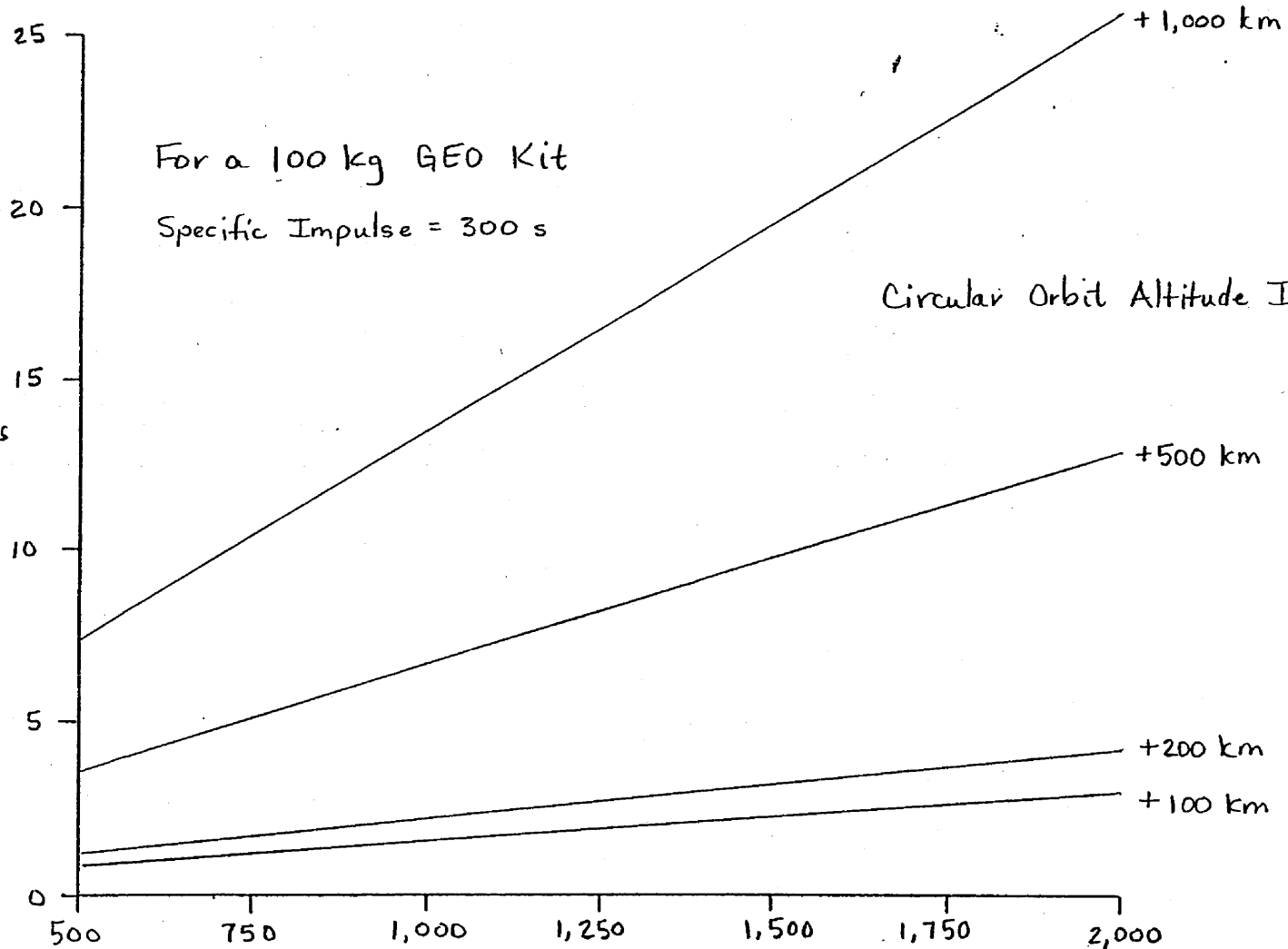
# Propulsive Requirements for Satellite Disposal from GEO

447

Propellant Mass  
Required (kg)

For a 100 kg GEO Kit  
 Specific Impulse = 300 s

Circular Orbit Altitude Increase



GEO Spacecraft Mass (kg)

# Preliminary Mission Analysis

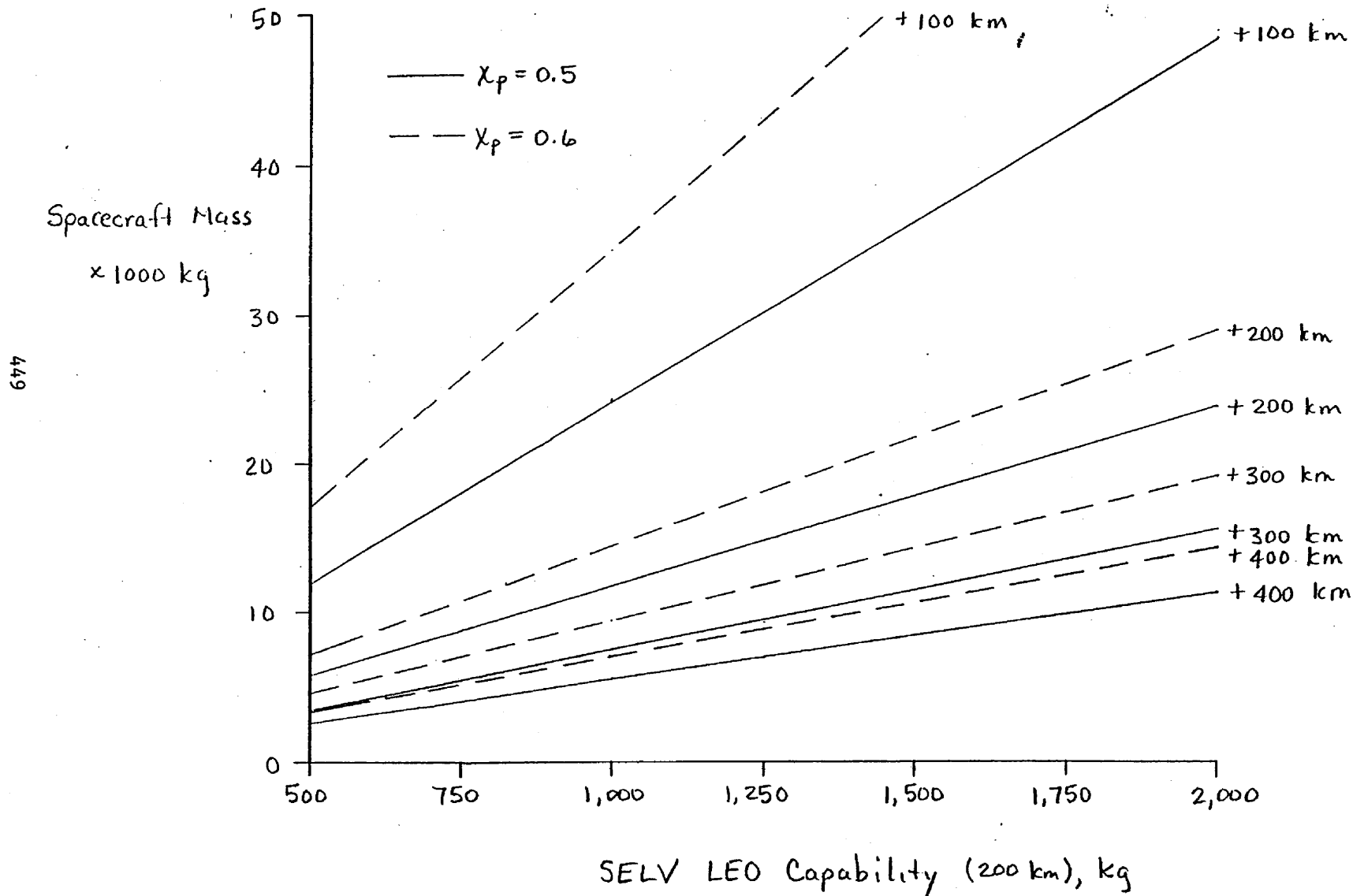
## Reboost--*Stranded Satellite Rescue*

Assuming a SELV places a propulsion "kit" in LEO, what is the bound on the mass of a spacecraft that it could dock with and insert into a GTO?

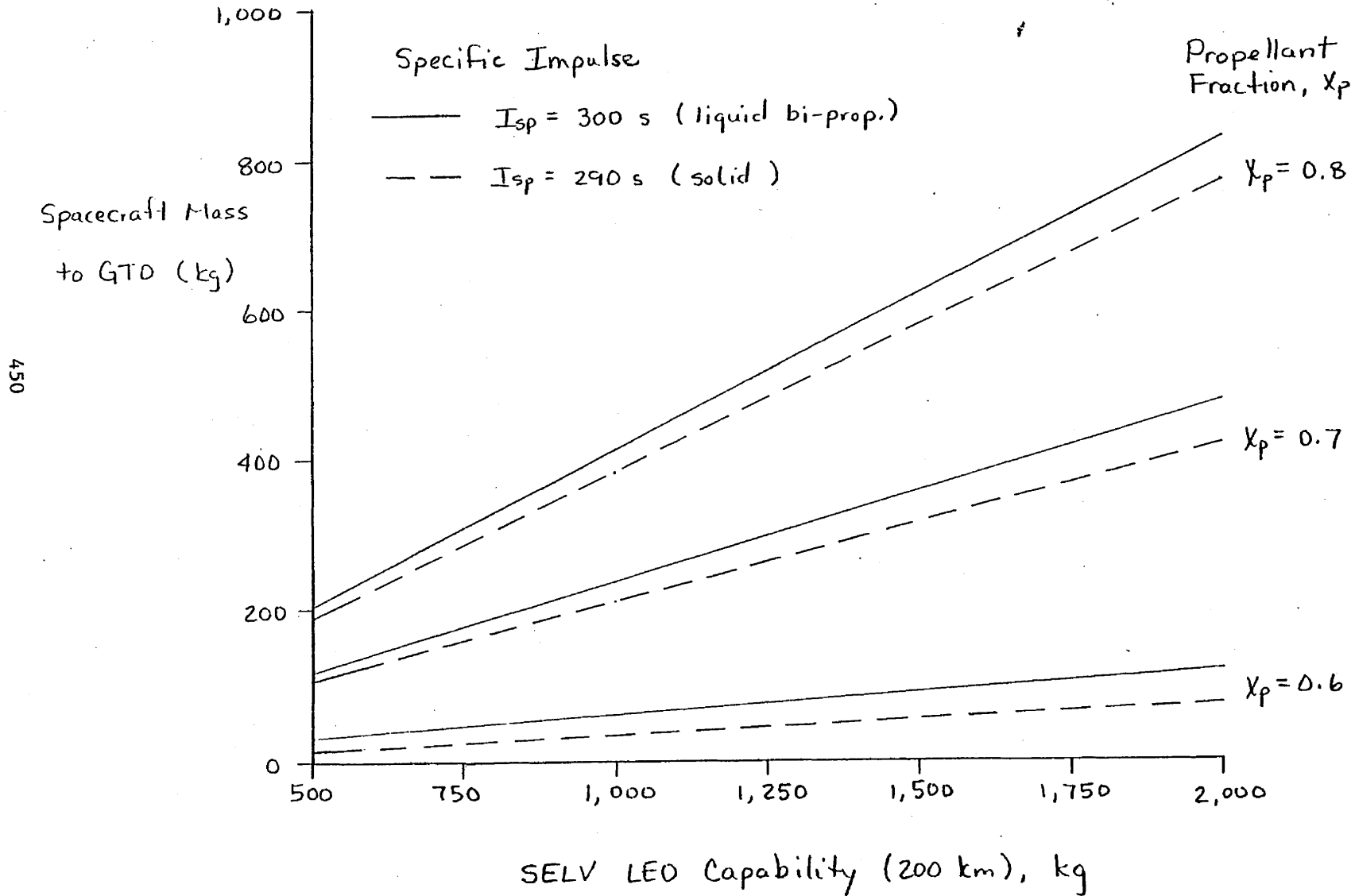
- Satellite initially stranded in a 200 km circular orbit.
- Propulsion system specific impulse (Isp) limited to about 290 s for solids, 300 s for available small storable liquids.
- Propellant mass fractions (of total kit mass) between 60-80%
- Satellite inserted into GTO only--would have to utilize its own AKM or on-board RCS for circularization maneuver.
- The low insertion masses, taken with the need for the satellite to perform its own circ maneuver, make reboost of communications satellites unlikely.
- However, LEO reboost (and MEO) is easily doable.



# LEO Reboost Capability



# GTD Insertion Capability



## Preliminary Mission Analysis

<b>Mission Matrix</b>	<b>LEO</b>	<b>MEO</b>	<b>GEO</b>
<b>Repair</b> - Restore - Replace - Supplement	YES (T)	YES (T)	POSSIBLY (T&P)
<b>Refuel</b>	YES	YES	YES (P)
<b>Deorbit/Disposal</b>	YES	NEED?	YES
<b>Delivery/Recovery</b>	YES (SSF)	N/A	N/A
<b>Retrieve</b> - Direct - via STS	SOME (P)	NO (P)	NO (P)
<b>Reboost</b>	YES	YES (P)	UNLIKELY (P)

Limiting Factors: P=performance, T=technology

## **Conclusions and Recommendations**

**For LEO missions, current SELV performance is sufficient for all of the mission types with the exception of retrieval--although indirect retrieval via the Shuttle is still a possibility.**

**For MEO missions, current SELV performance is sufficient for repair, refuel, and boost (for MEO satellites stranded in LEO by booster failure).**

**For GEO missions, the SELV top performers have performance approaching what is needed to do low-mass repair, refuel, and disposal missions.**

**Reboost of GEO satellites stranded in low orbits is possible, but only for smaller satellites which possess their own apogee kick maneuver capability.**

**Launching GEO missions from equatorial locations can provide about a 20% performance increase.**

## Conclusions and Recommendations

<b>Mission Matrix</b>	<b>LEO</b>	<b>MEO</b>	<b>GEO</b>
<b>Repair</b> - Restore - Replace - Supplement	YES (T)	YES (T)	POSSIBLY (T&P)
<b>Refuel</b>	YES	YES	YES (P)
<b>Deorbit/Disposal</b>	YES	NEED?	YES
<b>Delivery/Recovery</b>	YES (SSF)	N/A	N/A
<b>Retrieve</b> - Direct - via STS	SOME (P)	NO (P)	NO (P)
<b>Reboost</b>	YES	YES (P)	UNLIKELY (P)

Limiting Factors: P=performance, T=technology



# SESSION IV





# **Summary of the SELV-Based In-Space Operation Workshop**

## **October 18-19, 1993**

### **Hampton, VA**

#### **SESSION IV**

##### **Synthesis and Government Role**

457 The discussions in this session started with the request for additional missions that may not have been identified in the mission taxonomy presented by Davy Haynes. It was generally accepted that all apparent missions had been identified, with only a few additions offered from the floor. It was suggested that a LEO mission comprised of a servicer satellite capable of resupply of expendables or repair for a constellation of satellites should be added. Furthermore, the mission of boosting a stranded satellite from a useless transfer orbit, while captured in Mr. Haynes' categories, deserved particular emphasis due to the high payoff attending repair. This is particularly true for otherwise healthy communication satellites trapped in unintended geostationary transfer orbits.

Mr. Haynes expressed an opinion that rescue of such satellites may be outside the performance capabilities of SELV's. This proposition was discussed with the suggestion that analysis would probably clarify the issue.

The workshop was then asked to prioritize the missions in terms of financial impact, technology readiness, and practicality. Very little was developed with regard to the latter two categories, other than to note that most of the technology is currently available to do the missions, given the proper "design for servicing." Some other missions can possibly be done, but they must be approached on an individual basis.

With respect to financial impact, Mr. Jeff Cassidy noted that the great bulk of the market was in the highly accessible LEO orbits. Mr. Cassidy further noted that while the market was in LEO, these are virtually all uninsured Government satellites, and consequently of no interest to the insurers. Mr. Jack Koletty of EER noted that with the current government emphasis on commercialization such as "data buys," there was the very high likelihood that some of these LEO assets may find themselves in the hands of private owners. Mr. Koletty further asked whether it was Mr. Cassidy's understanding that these commercial space assets would or would not be insured. Mr. Cassidy allowed that he believed that, indeed, the assets would be insured and that the insurance companies would then be interested to see what might be proposed vis-a-vis servicing.

Mr. Cassidy noted to the group that while many assets might well benefit from servicing, most of these were not insured. While servicing of uninsured assets is obviously of no interest to his company, that was most probably not the case with their uninsured owners (the Government).

As far as the Government role and the protection of proprietary rights in the presence of public expenditures was concerned, the group felt that both taxpayers and companies could easily have their interests accommodated. It was asked, was this true even in the case of flight projects with multiple companies? The private company representatives agreed that sufficient safeguards were available and already in practice.

As far as the Government role is concerned, the company representatives agreed that access to Government facilities was important and that cooperative activities would be important in developing an In-Space Operations industry. Nevertheless, the role of the Government in providing seed money and particularly some flight demonstrations was acclaimed as the most important single thing to be done. The experience of the undersea oil drilling industry backs this notion in that early technology efforts by the Government served as catalyst for an industry that is now indispensable in undersea operations.

It was suggested by Mr. Larry Langston of Lockheed that the Government might wish to make a CBD announcement asking for information from companies related to developing a broad range of suggestions with respect to ways the Government can more effectively work with private industry.

At 3:00 pm, Dr. Katzberg thanked the participants for their enthusiastic participation, noted the intention of producing a Proceedings, and the intention of keeping the group informed of any follow-on activities. That done, Dr. Katzberg adjourned the workshop.

REPORT DOCUMENTATION PAGE			Form Approved OMB No. 0704-0188	
<small>Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188), Washington, DC 20503.</small>				
1. AGENCY USE ONLY (Leave blank)		2. REPORT DATE September 1995		3. REPORT TYPE AND DATES COVERED Conference Publication
4. TITLE AND SUBTITLE Prospects for Commercialization of SELV-Based In-Space Operations			5. FUNDING NUMBERS 477-50-00-01	
6. AUTHOR(S) Stephen J. Katzberg, James L. Garrison, Jr., Compilers				
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)  NASA Langley Research Center Hampton, VA 23681-0001			8. PERFORMING ORGANIZATION REPORT NUMBER	
9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES) National Aeronautics and Space Administration Washington, DC 20546-0001			10. SPONSORING / MONITORING AGENCY REPORT NUMBER NASA CP-10179	
11. SUPPLEMENTARY NOTES				
12a. DISTRIBUTION / AVAILABILITY STATEMENT Unclassified - Unlimited Subject Category 15			12b. DISTRIBUTION CODE	
13. ABSTRACT (Maximum 200 words) <p>A workshop was hosted by the Langley Research Center as a part of an activity to assess the commercialization potential of Small-Expendible-Launch-Vehicle-based in-space operations. Representatives of the space launch insurance industry, industrial consultants, producers of spacecraft, launch vehicle manufacturers, and government researchers constituted the participants. The workshop was broken into four sessions: Customers, Small Expendible Launch Systems, Representative Missions, and Synthesis-Government role. This publication contains the presentation material, written synopses of the sessions, and conclusions developed at the workshop.</p>				
14. SUBJECT TERMS Space Operations, Logistics, Space Commercialization, Robotics			15. NUMBER OF PAGES 470	
			16. PRICE CODE A20	
17. SECURITY CLASSIFICATION OF REPORT Unclassified	18. SECURITY CLASSIFICATION OF THIS PAGE Unclassified	19. SECURITY CLASSIFICATION OF ABSTRACT Unclassified	20. LIMITATION OF ABSTRACT	







NASA Technical Library



3 1176 01423 0628